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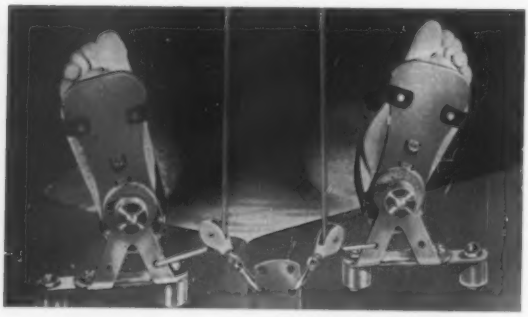

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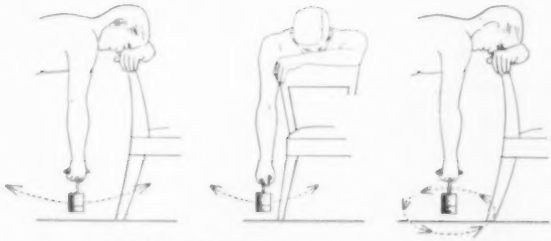

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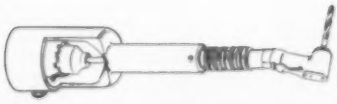

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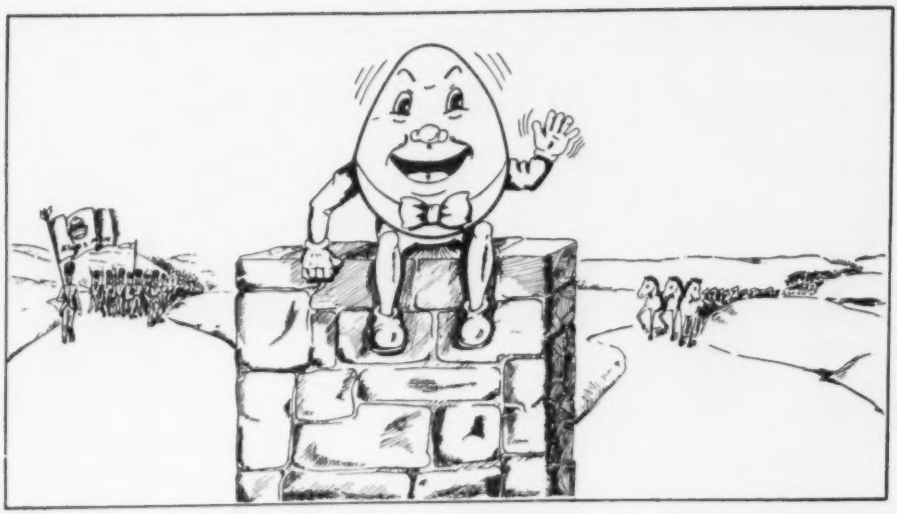

Humpty Dumpty sat on a wall
Humpty Dumpty had a great fall,
All the king's horses and all the king's men
Couldn't put Humpty Dumpty together again

Because . . . In that day they did not have

The RUSH®
MEDULLARY PIN
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THE JEWETT HYPEREXTENSION BACK BRACE*

FOR

1. Uncomplicated Compression Fractures and/or Kummell's Disease
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3. Marie Strumpell's Arthritis of the spine
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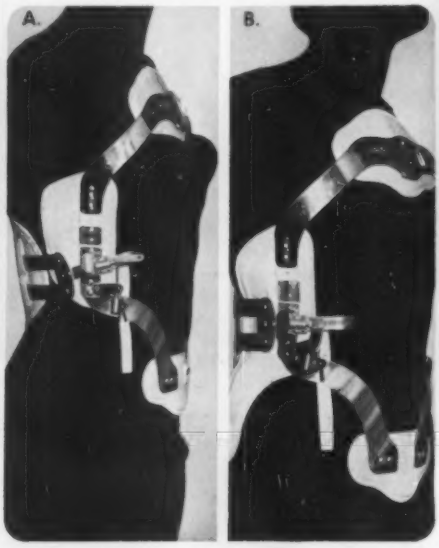

A. Standard Hyperextension Model
B. The Post Lumbo-Sacral Fusion Model

RIGID — ADJUSTABLE — LIGHT WEIGHT — WASHABLE

You are also invited to inquire about:

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- The MYO-VENT Collar
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when the patient requires intermediate cervical support

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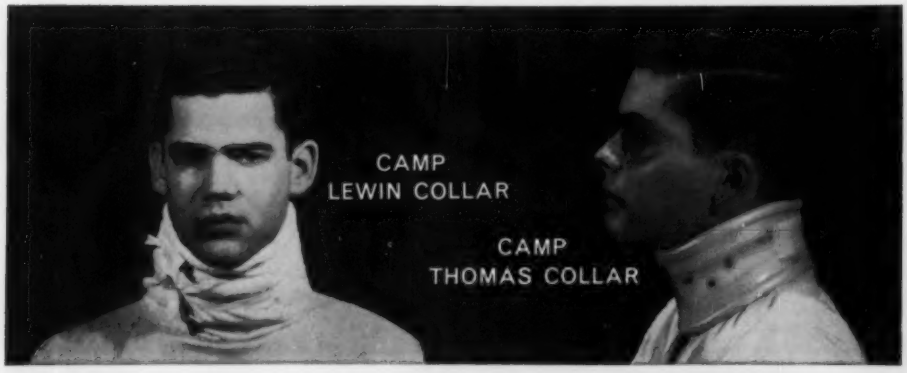
Camp's non-toxic, washable, light plastic Thomas Hyperextension Collar features new easy-to-adjust Velcro closure. The supporting base and top portion of the collar are edged with Don Lon covered foam rubber for comfort and durability. When prolonged, non-rigid hyperextension is indicated in treatment of cervical myoradicular syndrome, subluxation, arthritis or brachial plexus injuries, the Thomas Collar offers therapeutically effective relief. Allows partial lateral head movement. Made in six circumferences and five heights.



S. H. Camp and Company, Jackson, Michigan

S. H. Camp and Company of Canada, Ltd., Trenton, Ontario

CAMP

3 vital considerations in relief of pain and restoration of function in hip pathology

Election of Arthroplasty

"Artificial prostheses for replacement of the upper end of the femur deserve a place in our armamentarium of treatment of hip disease."[1]

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"We believe that the cobalt-chrome alloys [VITALLIUM] have in clinical experience proved to be so superior in all respects to the existing stainless steels that they should now be very seriously considered for all surgical implants."[2]

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"... the Austin Moore intramedullary VITALLIUM prosthesis [is] one of the best prostheses available at the present time."[3]

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For further information about VITALLIUM appliances, consult your surgical dealer or write to Austenal Company.

REFERENCES: 1. Gaenslen, F.G.: Wisconsin Med. J. 59:181, 1960. 2. Scales, J. T., and Zarek, J.M.: J. Bone & Joint Surg. 37B:527, 1955. 3. Matchett, F.: Rocky Mountain M.J. 56:47, 1959. 4. Callahan, J.J.: S. Clin. North America, W.B. Saunders Co., Philadelphia, Feb. 1957, p. 135.

What is **Vitallium?**

VITALLIUM is a registered trade mark of the Austenal Company applied to certain cobalt-chromium alloys and to surgical appliances made from those alloys.

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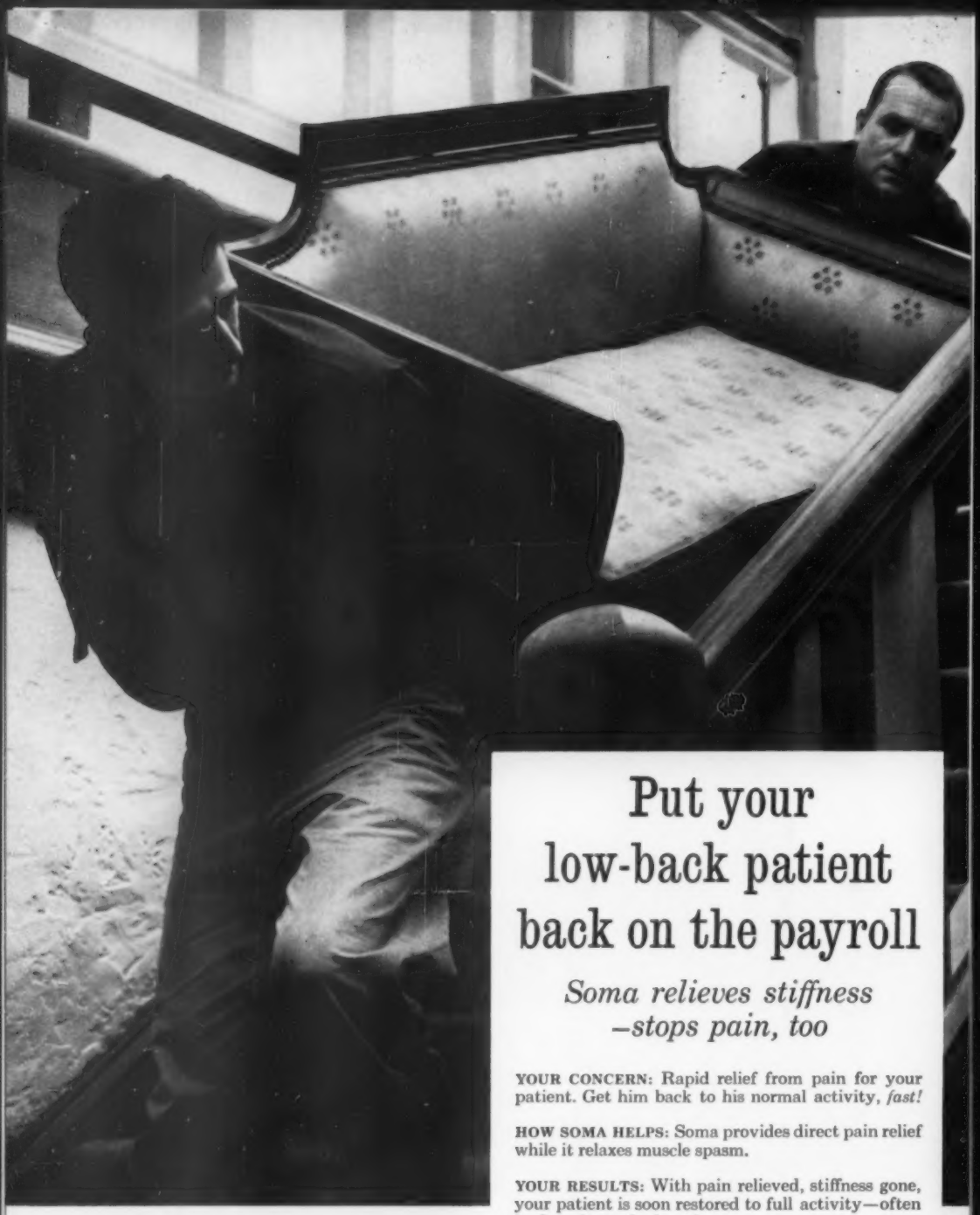

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YOUR CONCERN: Rapid relief from pain for your patient. Get him back to his normal activity, *fast!*

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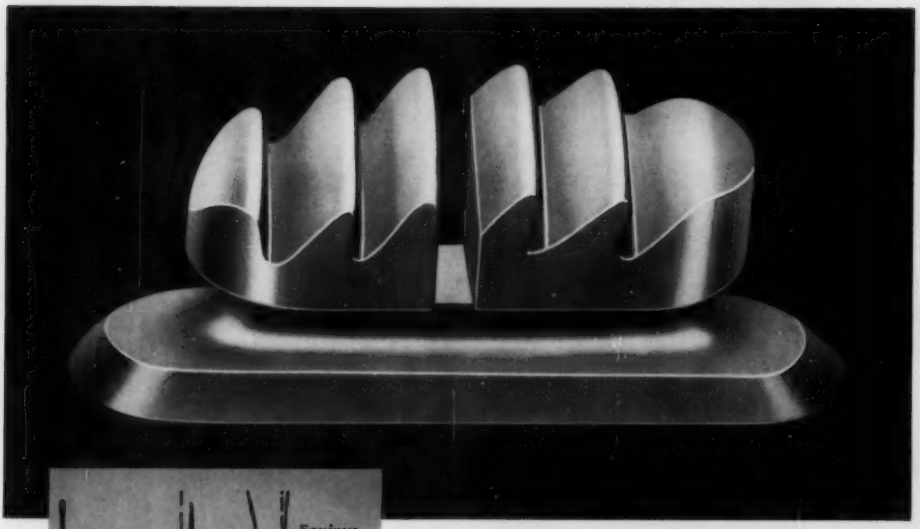

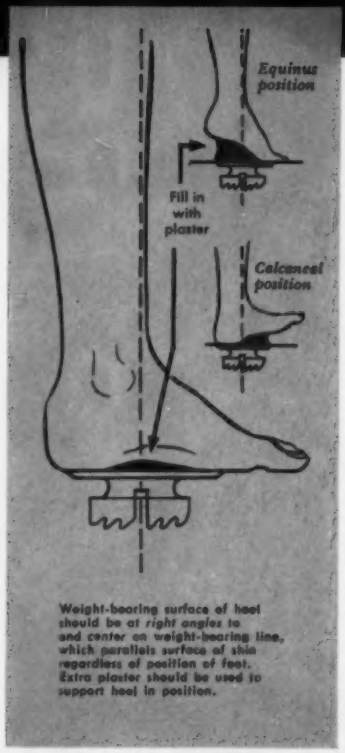
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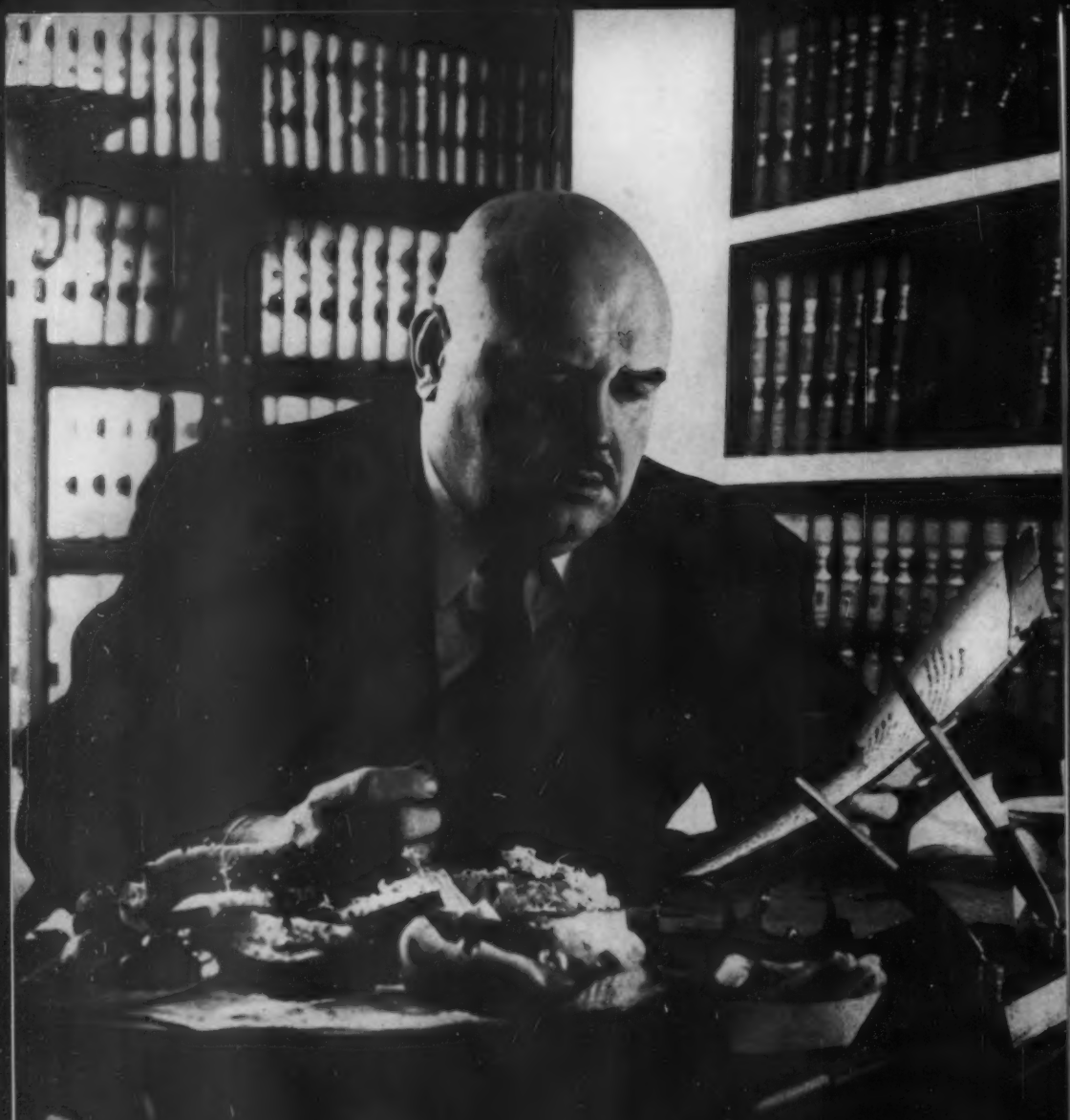

for "special-problem" patients...when corticosteroid therapy is indicated

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Since it does not produce edema, triamcinolone is useful in rheumatoid arthritis patients with cardiac decompensation who need steroid therapy. (Hollander, J. L.: *J.A.M.A.* 172:306 [Jan. 23] 1960.)

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Triamcinolone may be included among the currently available antirheumatic steroids having the least tendency to cause sodium retention. (Ward, L. E.: *J.A.M.A.* 170:1318 [July 11] 1959.)

Hypertension did not result from triamcinolone therapy. Existing hypertension was reduced sometimes. This may have been due to lack of sodium retention. (Freyberg, R. H.; Berntsen, C. A., Jr., and Hellman, L.: *Arthritis & Rheumatism* 1:215 [June] 1958.)

Precautions: Collateral hormonal effects generally associated with corticosteroids may be induced. These include Cushingoid manifestations and muscle weakness. However, sodium and potassium retention, edema, weight gain, psychic aberration and hypertension are exceedingly rare. In the treatment of rheumatoid arthritis, dosage should be individualized and kept at the lowest level needed to control symptoms. Dosage should not exceed 36 mg. daily without potassium supplementation. Drug should not be withdrawn abruptly. Contraindicated in herpes simplex and chicken pox.

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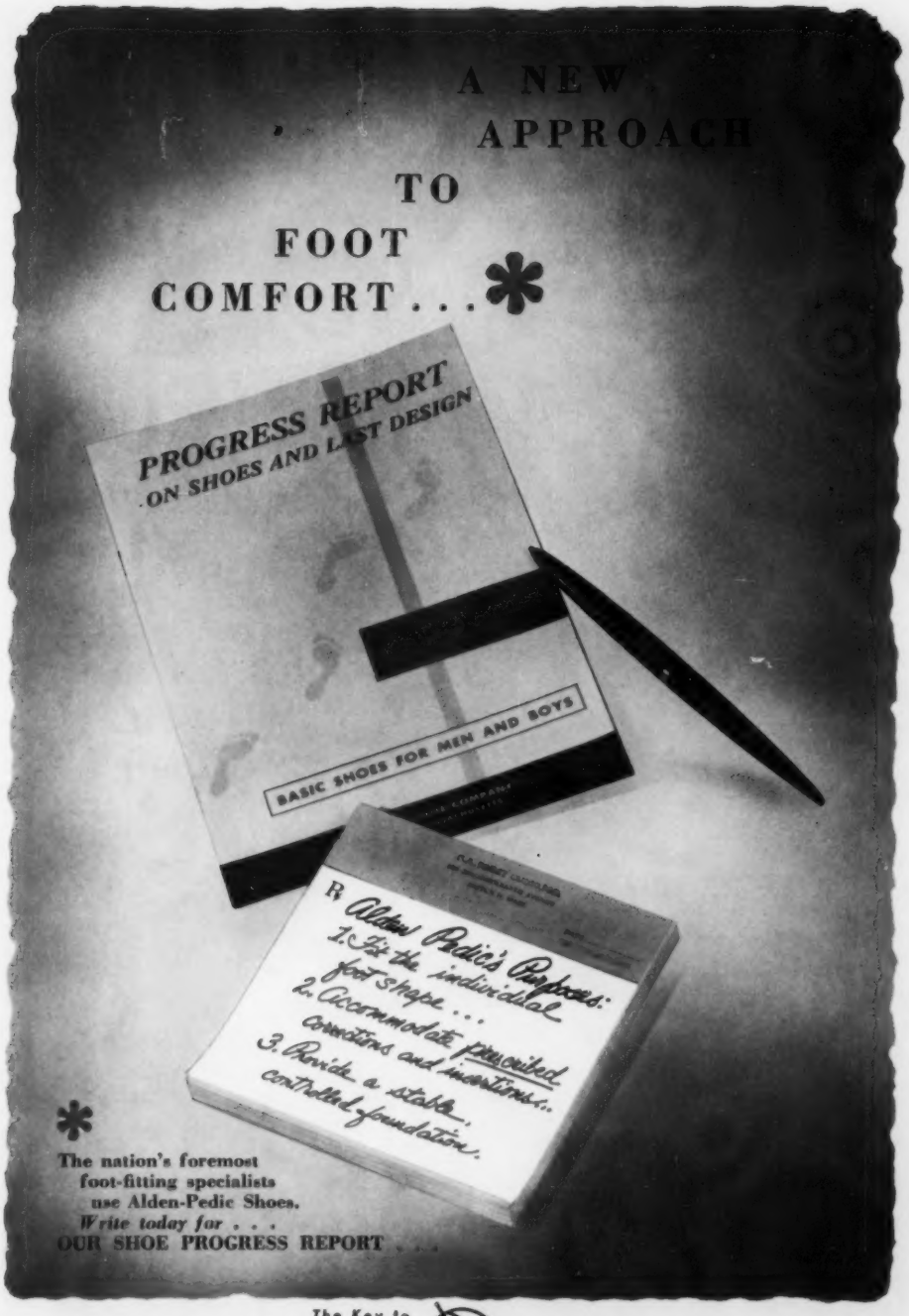
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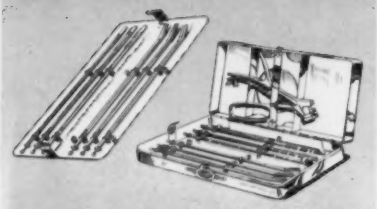

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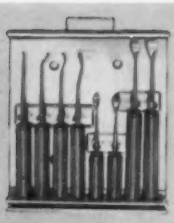

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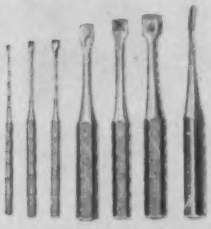

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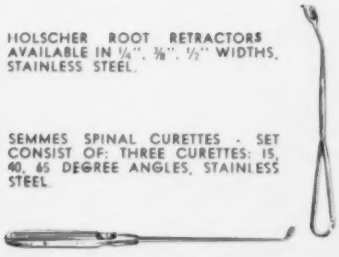

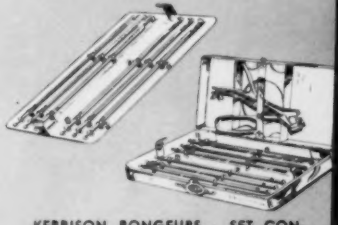

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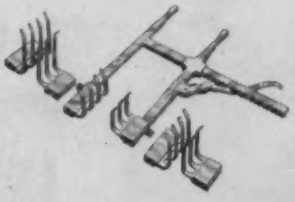

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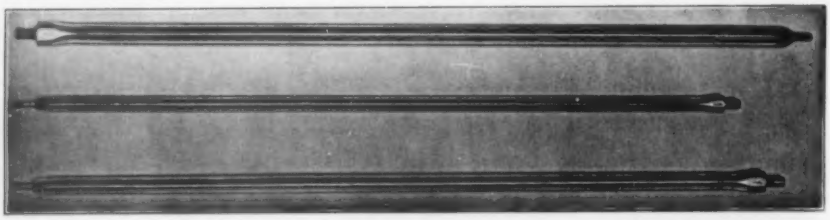

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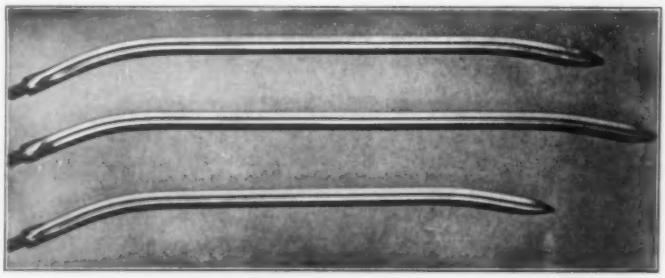

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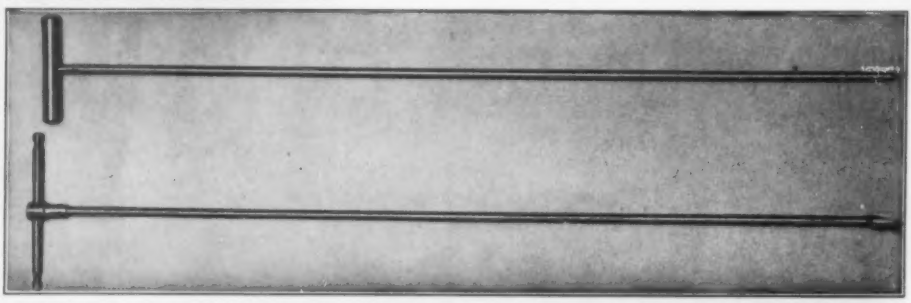

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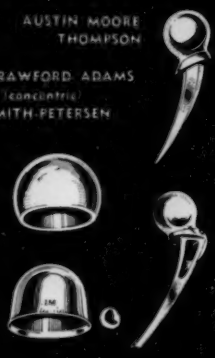

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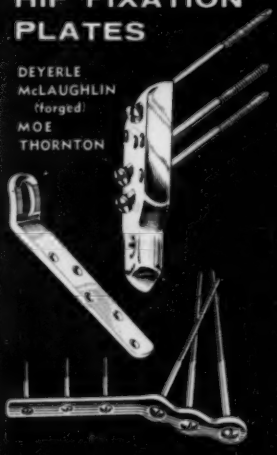

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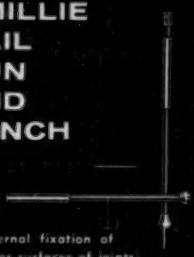

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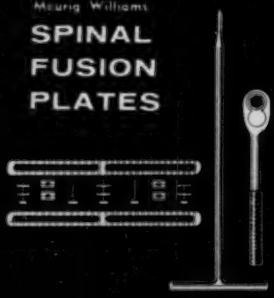

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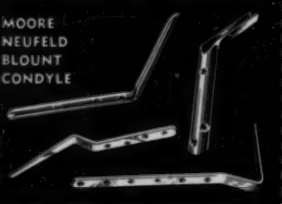

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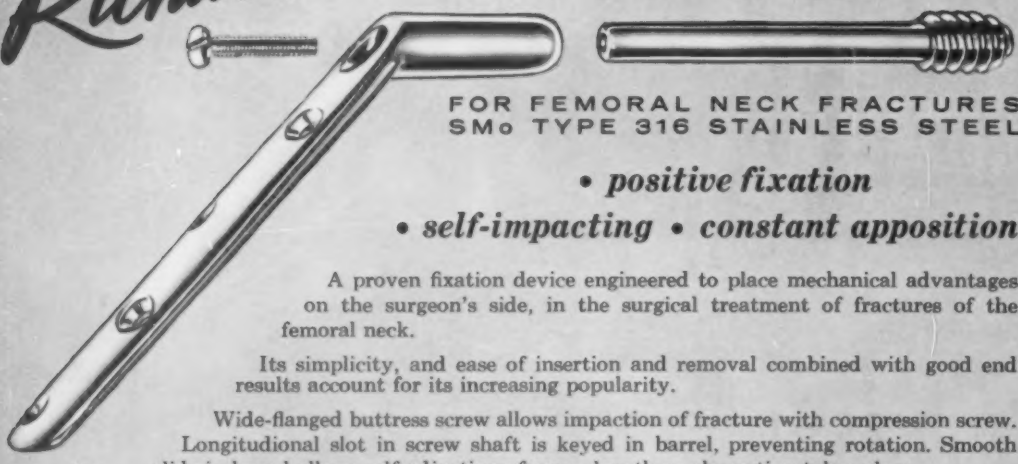

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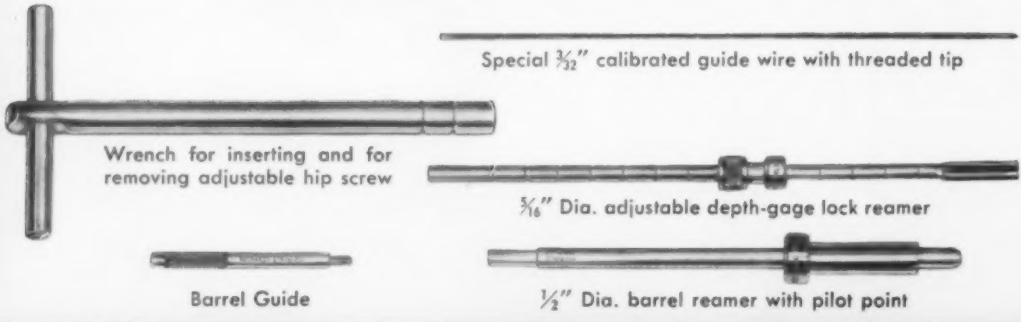

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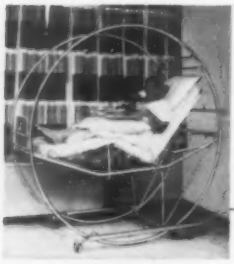

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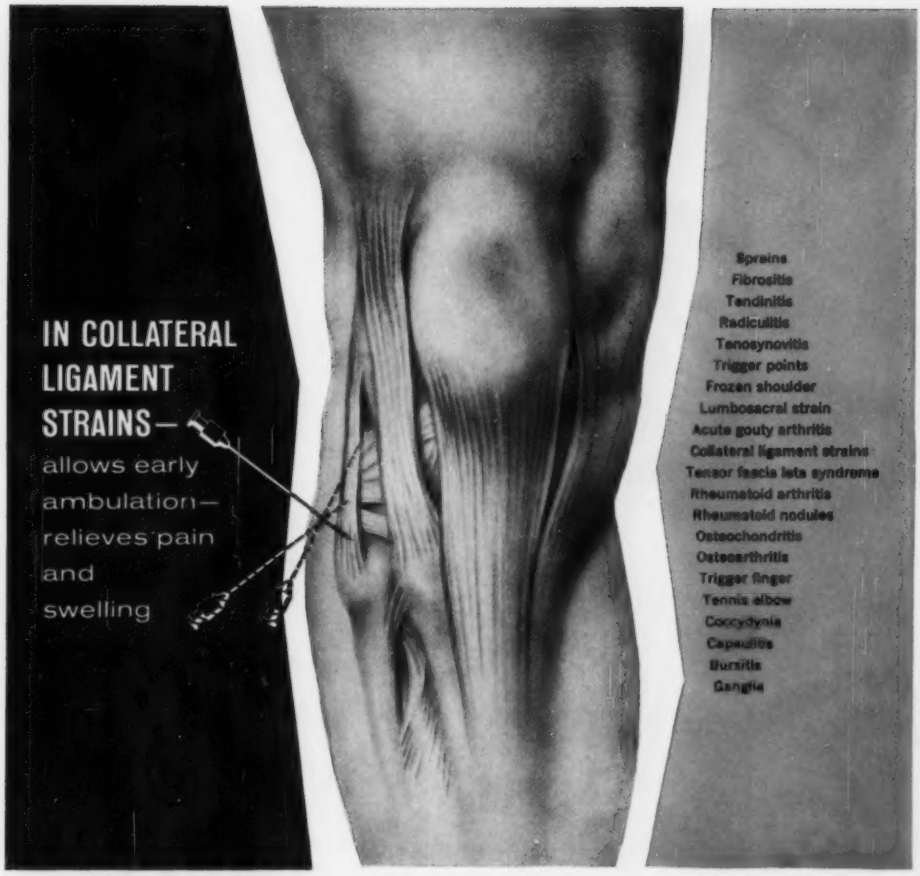

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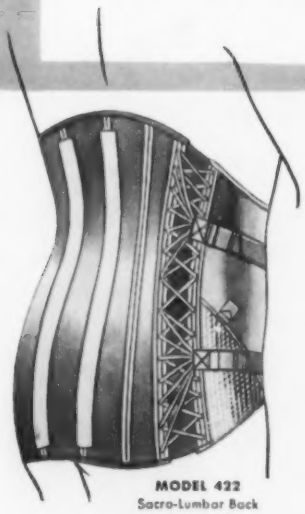

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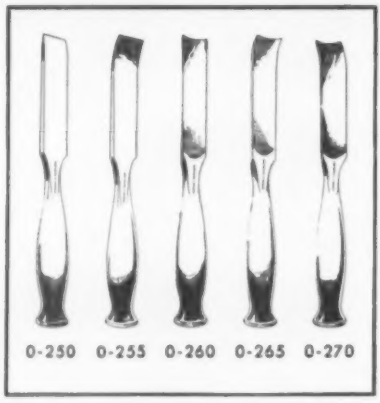

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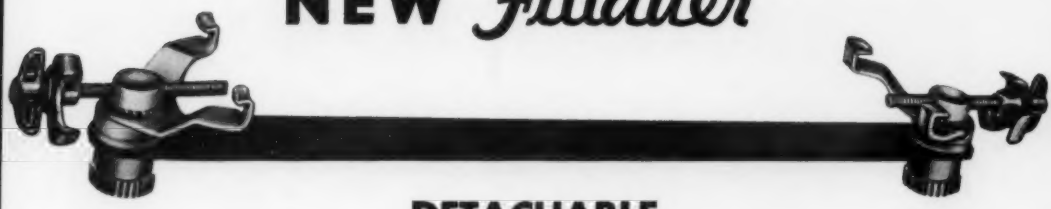

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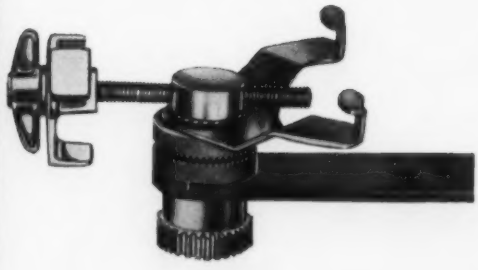

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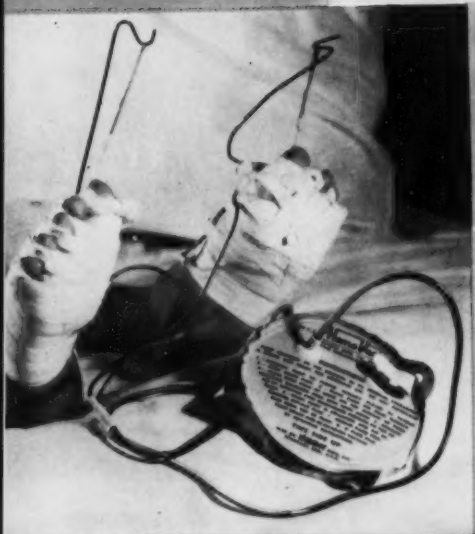

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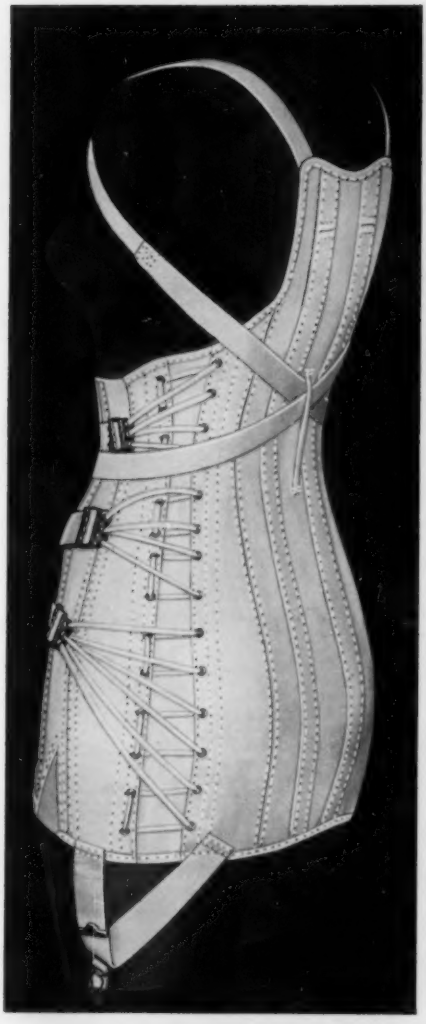

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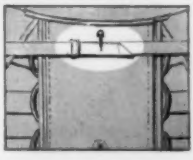

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The Journal of
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American Volume

Role of the Trunk in Stability of the Spine*†

BY J. M. MORRIS, M.D., D. B. LUCAS, M.D., AND B. BRESLER, M.S.,
SAN FRANCISCO, CALIFORNIA

From the Biomechanics Laboratory, University of California, San Francisco

The human spine may be frequently subjected to large forces. The mechanisms of muscular support which normally enable it to tolerate these forces have not been well understood. The role of the compartments of the trunk (thorax and abdomen) in helping to provide stability of the spine has therefore been investigated.

The spinal column serves as a sustaining rod for maintenance of the upright position of the body and, as such, is subjected to a complex system of forces and stresses of different types. This column may be considered to have both an intrinsic and an extrinsic stability. Intrinsic stability is provided by the alternating rigid and elastic components of the spine which are bound together by the systems of ligaments, whereas extrinsic stability is provided by the paraspinal and other trunk muscles.

It has been shown that the ligamentous spine may be considered to be a modified elastic rod. As such, it obeys the physical laws which apply to elastic rods. It has also been shown that the critical load value for the isolated ligamentous spine, fixed at the base, is approximately four and a half pounds, or much less than the weight of the body above the pelvis. If the load is increased further, buckling occurs [6]. The stability of the spine is therefore dependent largely on the action of the extrinsic support provided by the trunk muscles.

When one compares the forces to which the back (especially the lumbosacral area) is subjected with the force that the spine is able to tolerate experimentally, there is a discrepancy that is difficult to explain.

If the nucleus pulposus of the fifth lumbar disc is considered as the fulcrum of movement and a heavy weight is lifted with the hands, the arms and trunk form a long anterior lever. The weight being lifted and the weight of the head, arms, and upper part of the trunk are balanced by the contraction of the deep muscles of the back acting through a much shorter lever arm—the distance from the center of the disc to the center of the spinous process. With these factors in mind, the force that results when a 170-pound man lifts a 200-pound weight may

* One of the four Vernon P. Thompson Resident-Training Program award-winning papers read in part at the Annual Meeting of the Western Orthopedic Association, Coronado, California, October 26, 1960.

† This work was supported by Veterans Administration Contract V1005M–2075.

be computed. Conditions that may be assumed are that the weight is lifted at a distance of fourteen inches from the lumbosacral disc and that flexion of the spine at the pelvis is 40 degrees. It may also be assumed that in a man of this weight the head, neck, and upper limbs weigh thirty pounds (17.7 per cent of body weight) and that the portion of the trunk above the disc between the fifth lumbar and the first sacral vertebrae weighs fifty-one pounds (30 per cent of body weight)[3]. The head, neck, and upper limbs are attached to the top of the spine and may be considered to act at a distance of approximately eighteen inches from the fulcrum. The weight of the trunk may be considered to act seven inches from the fulcrum. Then, with use of these measurements alone, omitting the role of the trunk, the force on the lumbosacral disc can be calculated to be 2,071 pounds (Appendix 2 and Fig. 10).

In experimental studies of segments of the isolated ligamentous spine, structural failure occurred when forces of considerably less magnitude were applied [2,7]. Compression tests on two vertebral bodies with their intervening disc resulted in failure of the segments of spines, from subjects under forty years of age, under compressive loads ranging from 1,000 to 1,710 pounds. In older subjects the critical level was sometimes reduced to as little as 300 pounds.

Evidence of failure is often difficult to see either on gross examination or on the roentgenogram. It may consist of compression of a few spicules of bone, cracks in the end-plate, or, sometimes, collapse of the plate.

It is noteworthy that when the annulus is complete, its elastic limits cannot be exceeded without vertebral fracture. The end-plate is most susceptible to the forces on the spine, and it is generally this structure which gives way first.

The vertebral body itself is the next most susceptible portion of the segment under study and usually collapses before herniation of the nucleus through the annulus [7].

STATEMENT OF HYPOTHESIS AND SCOPE OF STUDY

The question arises how the lumbar vertebrae and discs are able to withstand the amount of force that can be imposed. One possible explanation lies in considering the spine as a segmented elastic column supported by the paraspinal muscles. This column is attached to the sides of and within two chambers: the thoracic and abdominal cavities, separated by the diaphragm. The thoracic cavity is filled largely with air, and the abdominal cavity with a semifluid mass. The action of the trunk muscles converts these chambers into nearly rigid-walled cylinders of (1) air and (2) liquid and semisolid material. Both these cylinders are capable of resisting a part of the force generated in loading the trunk and thereby of relieving the load on the spine itself.

To test this hypothesis, the action and effects of action of the muscles of the thorax and abdomen have been investigated under various conditions of loading of the trunk. These conditions may be divided into two categories: dynamic loading (lifting weights) and static loading (pulling on a strain ring). The intrathoracic and intra-abdominal pressures generated during loading were recorded simultaneously, as was the electrical activity of the trunk muscles. For dynamic loading the subjects' angles of trunk flexion for given portions of the recorded data were determined photographically, and for static loading four positions of trunk flexion were used.

METHODS AND MATERIALS

Ten healthy male subjects took part in these experiments.

The intrathoracic pressure was obtained by means of an open-tip polyethylene

catheter (No. 190) placed within the esophagus, and the intra-abdominal pressure by means of a similar catheter placed within the stomach. The ends of these catheters were covered with small rubber esophageal balloons which were partially inflated with a small amount of air to prevent occlusion of the openings of the catheter by the mucosal lining of the organs.

It is realized that the pressures obtained from the esophagus and stomach may not be exactly the same as the intrathoracic and intra-abdominal pressures. It is, however, reasonable to assume that the pressure changes as recorded from within these organs reflect those that occur within the two body cavities.

The placement of the catheters was determined by having the subject inspire maximally. The catheter within the lower part of the esophagus recorded a negative pressure, while that within the stomach recorded a positive pressure. In addition, the changes of pressure within the lower part of the esophagus, caused by the heart beat, frequently could be used to help determine the placement of the catheter.

Records of the electrical activity of the trunk muscles were obtained by use of embedded wire electrodes consisting of insulated fine copper wire (No. 34). This wire was threaded through a No. 25 hypodermic needle, the insulation removed from the tip of the wire, and a small hook made in the end of the wire over the short side of the bevel of the needle. The needles with their contained wire electrodes were then sterilized.

After suitable preparation and local anesthetization of the skin, two needles and electrodes were inserted approximately two centimeters apart into each muscle to be studied. The needles were then withdrawn, leaving the wire electrodes with their hooks embedded within the muscles. These were easily removed subsequently by gently pulling on the wires and straightening out the hooks.

The activity of the intercostals, the abdominal obliques, the rectus abdominis, and the deep muscles of the back was recorded simultaneously. The intercostal space between the fifth and sixth or sixth and seventh ribs on the right side was used for obtaining the intercostal activity. The activity of the abdominal obliques was obtained from the right upper quadrant of the abdomen. No attempt was made to estimate depth of the needle so as to differentiate activity of the external oblique from the internal oblique or transversus abdominis. The activity of the rectus abdominis was obtained in the right epigastrium and that of the deep muscles of the back from the main muscle mass of the sacrospinalis at the level of the second to third lumbar vertebra.

Loading of the trunk was accomplished by two methods. In the first (dynamic), the subject lifted weights, in the form of bar bells, of from zero to 200 pounds, in increments of fifty pounds. The weights were lifted from the floor to the height of the freely hanging hand with the subject in the erect position. The lifting was done both with the knees flexed and the spine relatively straight and with the knees straight and the spine flexed. When the heavy weights (150 to 200 pounds) were lifted, the subjects were frequently unable to maintain the second position and lifting was accomplished by partially flexing the knees and spine.

In order to fix the subject's angle of flexion with reference to a given portion of the recorded data, motion pictures of two subjects were made with a thirty-five-millimeter camera which simultaneously photographed a clock in the field of view and a frame on which there were vertical and horizontal lines in a plane parallel to the subject's sagittal plane. The clock had one-second, six-second, and thirty-second sweep hands; the one-second sweep hand triggered a pulse every second which was recorded together with the other data.

The one-second dial was divided into intervals of 1/100 second. The camera

TABLE I

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES STRAIGHT, SPINE FLEXED

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	10	32	83	102	143
JM	2	4	36	58	112	122
JM	3	4	36	84	104	128
MK	1	8	20	30	42	80
MK	2		20	42	44	72
BG	1		24	36	68	104
BG	2	8	24	48	70	104
CC	1		34	62	90	
CC	2	10	26	64	90	108
HL	1	14	16	50	90	172
BB	1	4	36	58	80	80*
RW	1	8	34	66	80	112
RD	1		28	52	120	120
BS	1	10	20	56	80	76
BE	1	8	46	118	148	168
BE	2	20	46	112	160	170
Mean		9	30	64	93	120

* 175 pounds lifted.

TABLE II

RELATIONSHIP OF INTRATHORACIC PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES STRAIGHT, SPINE FLEXED

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	2	20	53	63	62
JM	2	4	46	46	50	60
JM	3	2	30	38	56	52
MK	1	7	18	19	38	48
MK	2				28	40
BG	1		28	16	72	62
BG	2	2	14	30	40	36
CC	1		28	46	48	
HL	1		16			100
BB	1	10	60	70	38	37*
RW	1	6	16	36	60	66
RD	1		32	28	48	52
BS	1	6	18	34	64	46
BE	1	14			60	88
Mean		6	27	38	51	59

* 175 pounds lifted.

speed was thirty-two frames per second, allowing indexing of the position of the subject to the corresponding portion of the recording. By counting down from the one-second mark made by the clock, it was possible to fix the subject's position to within 1/100 second on the recorded data.

The second (static) method of loading the trunk was by means of pulling against a measurable fixed resistance (strain ring) up to a maximum of 200 pounds. Pulling on the ring was done with the trunk of the subject in four positions. In all positions the knees were held straight. The trunk was held first vertical and then flexed at 30, 60, and 90 degrees. The amount of pull or tension exerted on the strain ring was recorded simultaneously with the intracavitary pressures and electromyographic activity.

TABLE III

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES FLEXED, SPINE RELATIVELY STRAIGHT

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	10	108	118	136	134
JM	2	16	44	120	154	158
JM	3	12	50	92	144	156
MK	1	14	44	84	110	136
MK	2	20	30	94	116	144
BG	1	14	30	108	140	140
BG	2	15	38	110	144	150
CC	1	10	38	92	120	116
CC	2	16	44	140	124	148
HL	1	6	38	78	114	162
BB	1	6	40	80	86	88*
RW	1	18	92	104	108	118
RD	1	12	50	76	136	
BS	1	10	40	80	88	96
BE	1	10	66	138	186	200
BE	2	32	116	172	196	208
Mean		14	54	105	131	148

* 175 pounds lifted.

TABLE IV

RELATIONSHIP OF INTRATHORACIC PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES FLEXED, SPINE RELATIVELY STRAIGHT

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	4	44	44	56	47
JM	2	12	24	48	60	
JM	3	12	36	44	56	60
MK	1	10	40	44	58	60
MK	2	11	20	25	34	60
BG	1	8	20	34	64	60
BG	2	6	10	38	44	54
CC	1	8	34	48	50	56
HL	1		18	22	38	84
BB	1	0	22	26	26	26*
RW	1		22	62	42	54
RD	1	8	36	58	42	84
BS	1	8	20	40	48	56
BE	1		60	66	120	138
Mean		8	29	43	53	68

* 175 pounds lifted.

It was apparent from preliminary runs that the intracavitary pressure produced by loading the trunk must be considered in studying the forces acting on the spine. It was therefore decided to evaluate the effects of increasing the intra-abdominal pressure by means of externally applied pressure. For this purpose, a rubber bladder extending across the abdomen from one mid-axillary line to the other and from the xiphoid to the pubis was constructed. This bladder was placed within a non-elastic lumbosacral corset and inflated to the limit of comfort. The resting intra-abdominal pressure was thereby increased by approximately ten to fifteen millimeters of mercury.

RESULTS AND DISCUSSION

Although the weights lifted (dynamic loading) and the pull on the strain ring (static loading) may both exert a force of 200 pounds, there are, of course, a number of differences between these two methods. These differences are primarily in the positioning of the body components and the center of gravity, the amount of movement of the trunk, and the effects of inertia. The results obtained by the two methods of loading, as would be expected, reflect these differences.

Dynamic Loading of the Spine

A total of sixteen experimental runs was carried out on ten healthy male subjects. One subject was used for three runs, four subjects for two runs, and the remainder for one run each.

The intrathoracic and intra-abdominal pressures generated during the loading are given in Tables I through IV. Figure 1 is taken from a typical run as an illustration of the data obtained, with position *A* that of bending forward; *B*, beginning to lift the weight; *M*, lifting the weight from the floor; and *C*, standing upright with the weight at arm's length. It can be seen that when the subject bends over but lifts no weight there is little increase in the intra-abdominal and intrathoracic pressures. The small amount that may be present is probably due to passive compression of the viscera. As larger weights are lifted, the maximum pressures in both abdomen and thorax are progressively increased. The intra-abdominal pressure, however, rises more than that of the thorax with the heavier weights. As weights of 150 to 200 pounds are lifted, the amount of increase of pressure drops off as though a maximum limit were being approached.

As the weights are lifted, the pressures rapidly rise to the maximum and then drop when the upright position is reached. With all but the heaviest weights, the pressure in the abdomen drops almost to the resting level. With the heaviest weights a moderate pressure elevation is maintained in the upright position. These findings are similar to those of Bartelink. The spine seems to be able to tolerate the force of the smaller weights in the upright position with little support by the trunk, but with the heavier weights the trunk is needed to aid in the transmission of the force. As the weights are lowered, there is a second but lower peak of intracavitary pressures.

The intrathoracic pressure, although much less than the intra-abdominal, is more sustained and fluctuates less during lifting. Apparently, the rib cage becomes fixed by inspiration and muscle activity and remains so throughout the loading. The fact that the rib cage is not easily compressed beyond this fixed, stable position may account for the generally lower thoracic pressures.

The moving pictures made to correlate the position of the subject with the pressures and with the electromyographic activity demonstrated (as shown in Figure 1) that (1) there is little increase of pressure or muscle activity as the subject bends forward, (2) the pressures rise rapidly as the subject begins to strain to lift the weight, and (3) the maximum peak of pressure occurs at the moment the inertia of the weight is overcome and the weight is lifted from the floor. With the subject in the upright position and the weight at arm's length, the pressures again drop toward resting levels.

As is also shown in Figure 1, the trunk muscles become active simultaneously with the elevation of pressure. The activity of the investing trunk muscles obviously is important in the generation of these pressures. The activity of the rectus abdominis was generally noted to be less than that of the obliques or transversus, which have transverse components and compress the viscera by their con-

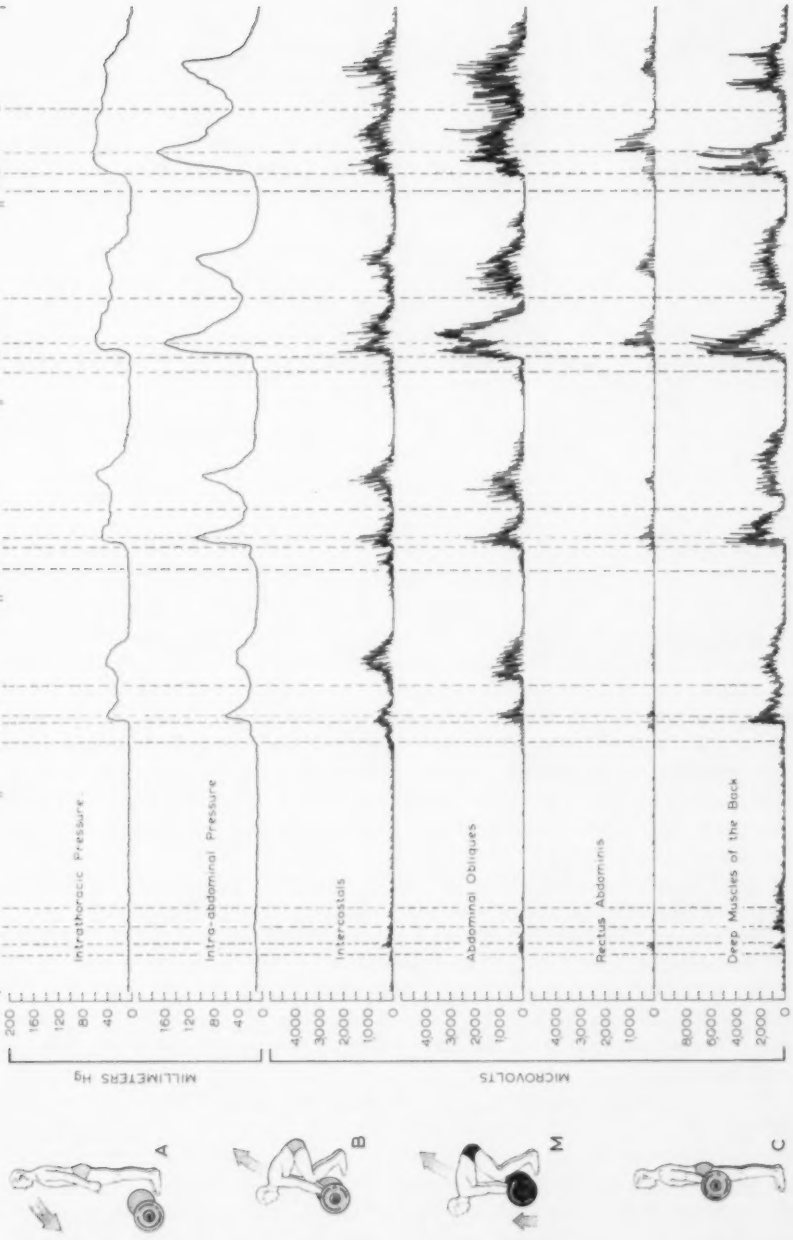

Fig. 1

Dynamic loading of the spine.

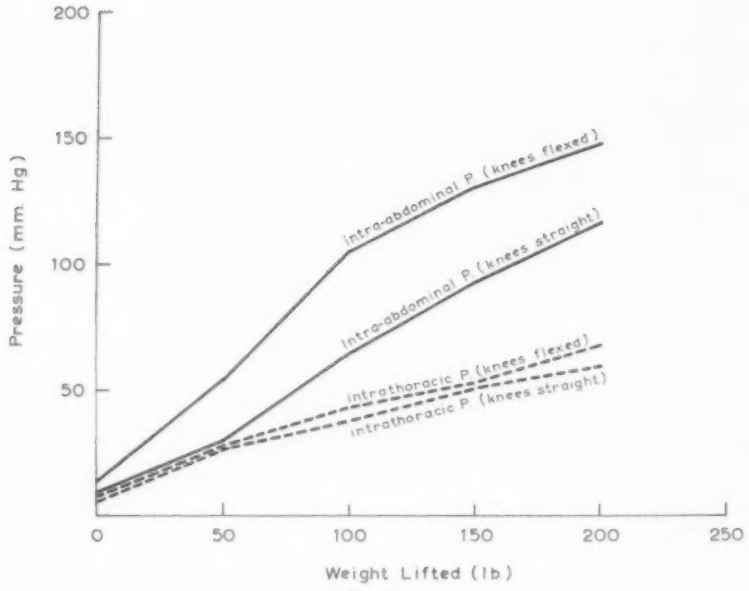

FIG. 2

Relationship of intracavitary pressures to dynamic loading of the spine.

traction. This was especially true when small weights were lifted or when the trunk was in a nearly vertical position. When the trunk was flexed and heavier weights were lifted, however, the activity of the rectus abdominis increased considerably. Presumably, it acts as a stabilizer, binding the rib cage to the pelvis and preventing pouching out of the abdominal viscera. The increase of activity in the flexed position was especially evident in tall subjects. (It should be noted that the electromyographic activity of a muscle increases when the muscle is shortened, even though there is no increase in tension.) The deep muscles of the back are, of course, seen to be active in extending the trunk and lifting the weights. As the weights and thereby the moment of the anterior lever and the force on the spine are increased, the activity of these muscles is increased. However, since none of these muscles contracts isometrically [5], the level of electrical activity as recorded cannot be accurately correlated with the amount of tension developed.

The two positions for the dynamic loading studies (knees flexed and spine relatively straight, knees straight and spine flexed) were fairly easily held by the subjects while lifting weights of up to 100 pounds. However, with weights of 150 to 200 pounds this was more difficult and most of the subjects found it necessary to flex the spine partially with the first method of lifting, and the knees with the second method.

The means of the maximum pressures generated during lifting of the various weights by the two methods are plotted in Figure 2. There was a considerable and consistent difference in the amount of intra-abdominal pressure generated during these two methods of lifting. It was more elevated when the weight was lifted with the knees flexed than with the knees straight. The intrathoracic pressures, however, were quite similar and much less than the intra-abdominal pressures.

No conditions of lifting the weights were imposed on the subjects other than that they lift in the two positions just outlined. No instructions were given as to holding the breath, inspiring maximally, or expiring. Much of the variability of

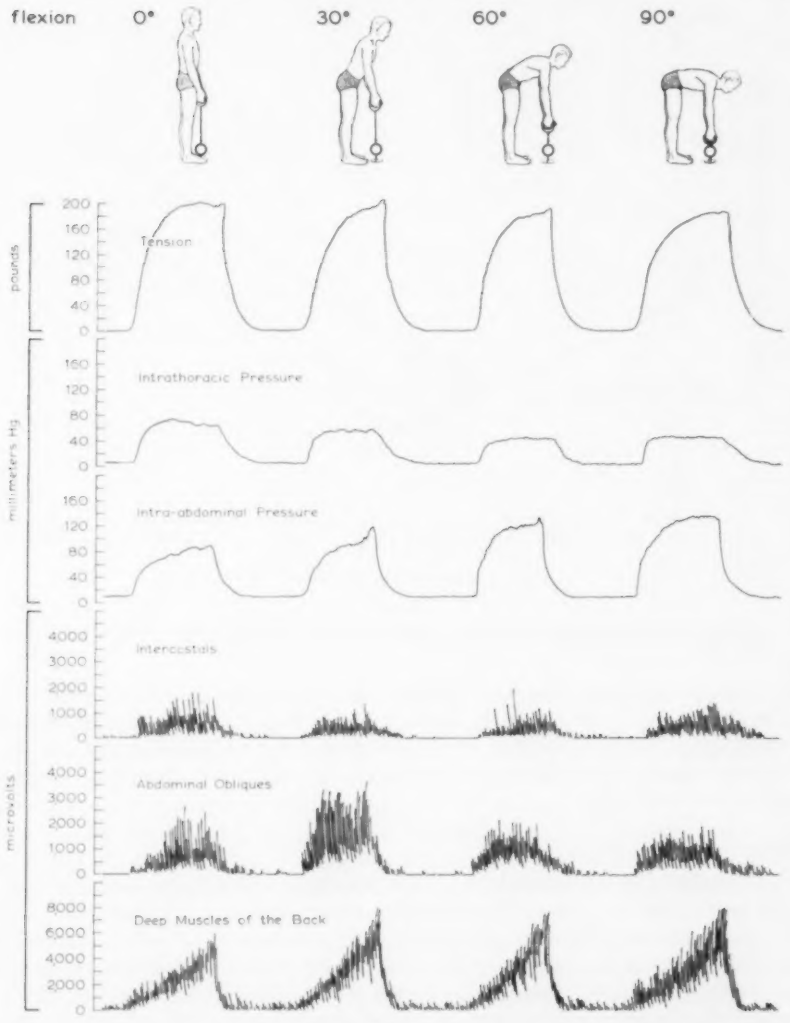

FIG. 3

Static loading of the spine.

the data presented in Tables I through IV may be accounted for by the fact that the subjects were allowed to lift the weights as naturally and easily as possible. Especially with the lighter weights, the amount of inspiration and holding of the breath affected the pressures. With the heavier weights, the conditions under which they could be lifted became more limited; for example, the depth of the inspiration became uniformly greater as the lift began, and the breath was held throughout the lift. Consequently, there is much better agreement in results of separate runs by the same subject when heavy weights were lifted than when lighter weights were lifted.

As can also be seen in the Tables, there is a considerable range in the values of the pressures for different subjects lifting the same weight (±30 to 35 per cent from the mean). There appears to be fairly good correlation between the size of

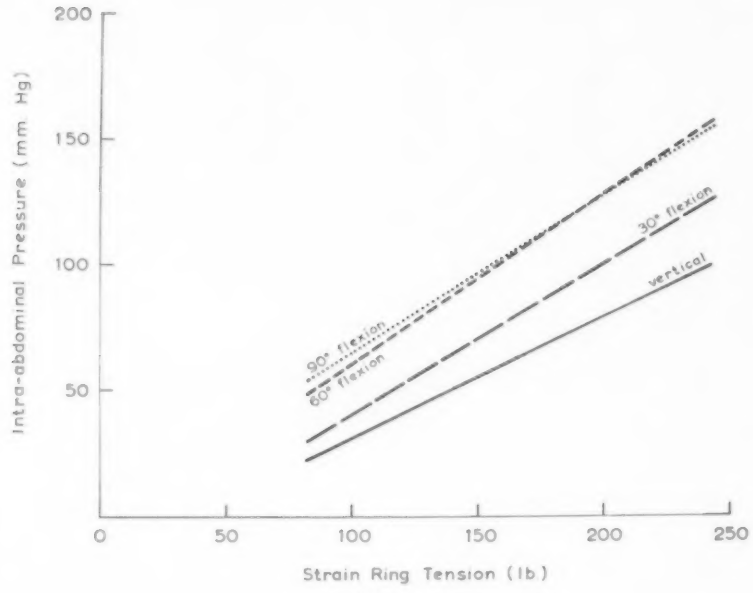

FIG. 4

Relationship of intra-abdominal pressure to static loading of the spine (without inflatable corset).

the subject and the amount of pressure generated. The lowest pressures were generally found in BB and BS, both of whom weighed between 120 and 130 pounds and who were five feet, three inches and five feet, four inches tall. The highest pressures were obtained in BE, who weighed 220 pounds and was six feet, two inches tall.

Static Loading of the Spine

For the study of static loading, sixteen experimental runs were performed with seven subjects. Tension imposed on a strain ring with the trunk vertical or in various degrees of flexion was simultaneously recorded with the intra-abdominal and intrathoracic pressures and the electromyographic activity of the muscles. It can be seen in Figure 3 that as the tension on the ring (or loading of the spine) is increased, the intracavitary pressures and electromyographic activity increase proportionately.

With the subject pulling on the ring in the upright position, the intra-abdominal and intrathoracic pressures were generally identical or nearly so. Evidently, equilibrium of pressures was established across the diaphragm with the subject in this position. As the subject progressively flexed the trunk on the thighs, the pressure in the abdomen tended to increase when any specific tension on the ring was maintained. The pressure in the thorax, however, remained the same or tended to decrease with progressive flexion of the trunk. The action of the obliques was generally fairly constant in the various positions, remaining proportionate to the pressure. The rectus abdominis was only slightly active in the vertical position, but its activity increased progressively with flexion of the trunk. The activity of the intercostals remained approximately the same or decreased slightly in the more flexed positions. The activity of the deep muscles of the back increased progressively with loading of the spine; it was somewhat less in the upright than in the flexed positions.

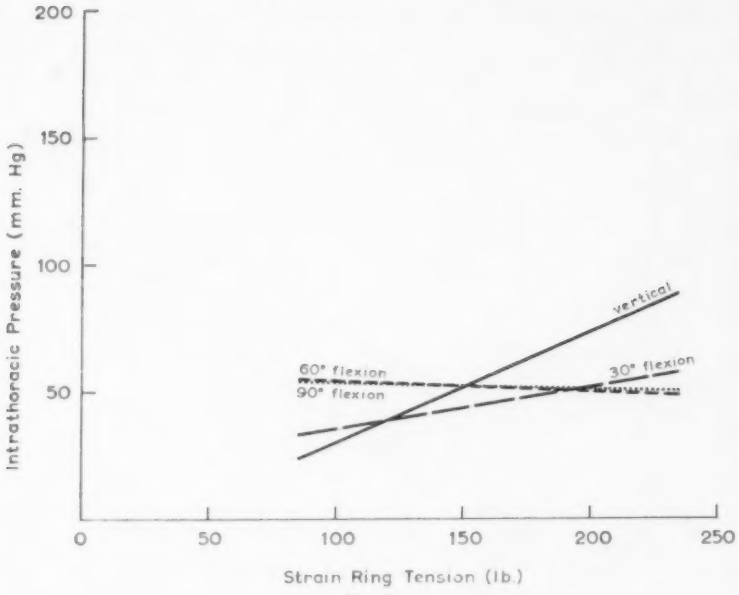

FIG. 5

Relationship of intrathoracic pressure to static loading of the spine (without inflatable corset).

The data obtained from the subjects in this series are difficult to compare and analyze for several reasons: (1) Both the amount of tension on the ring and the pressures generated were variable; (2) it was quite difficult to have a single subject pull exactly the same way on successive runs and even more difficult to have different subjects do so—frequently, there was a tendency for the subject to lean backward while pulling, thus using body weight in place of muscle activity to impose tension on the ring; and (3) small differences occurred in the amount of inspiration and of holding of the breath. The variability of the data was primarily due to the second factor—the position of the subject while pulling. The third factor played only a small role and then mainly when the load was small.

Despite this variability, a relationship between the intra-abdominal pressure and the position of the trunk during static loading is evident. The lines on the graph in Figure 4 were obtained from the data (maximum strain-ring tensions and maximum pressures in the four different positions) by the method of least squares. It can be seen that, for any specific tension on the ring, the intra-abdominal pressure increases with flexion of the trunk. There is, however, virtually no difference in the pressures obtained with the trunk flexed at 60 and 90 degrees.

This finding is clarified when it is recalled that when a weight is lifted in the flexed position, the spine forms a long anterior lever with the fulcrum in the lower lumbar part of the spine (Appendix 2 and Fig. 10). As the spine is progressively flexed, the length of the anterior component of this lever is increased, increasing the force on the lower part of the spine. The increased abdominal pressure in the flexed positions presumably reflects the larger forces being transmitted through the abdomen.

The slopes of the lines indicating the relationship between the intrathoracic pressure and tension on the strain ring were also determined by the method of least squares for each of the four positions studied (Fig. 5). In the upright posi-

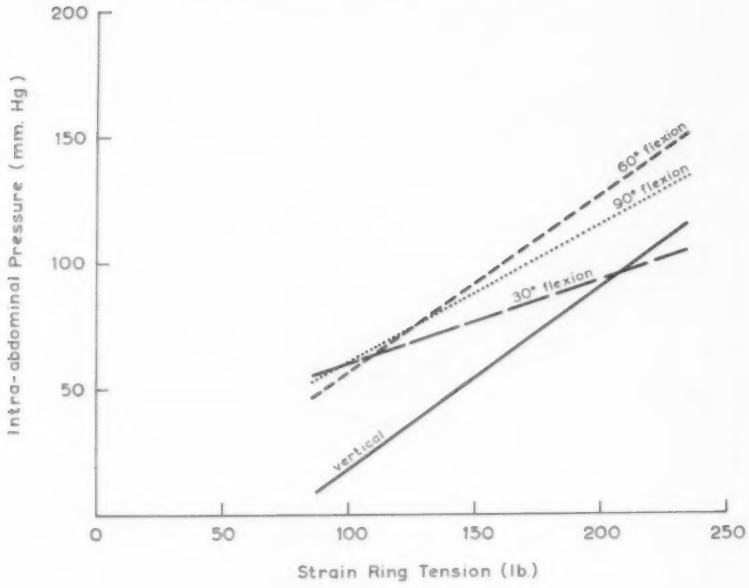

FIG. 6

Relationship of intra-abdominal pressure to static loading of the spine (with inflatable corset).

tion the relationship between the intrathoracic pressure and the tension is almost identical with that between the intra-abdominal pressure and the tension. Thus, equilibrium of the pressures of the two cavities occurs across the diaphragm in this position. When the trunk is flexed, however, the intrathoracic pressures are considerably lower than the intra-abdominal. It can also be seen that as the trunk assumes a more flexed position the degree of increase of intrathoracic pressure with further loading is diminished. When the trunk is flexed to 60 or 90 degrees, there is essentially no change in the intrathoracic pressure over the range of strain-ring tension studied here (100 to 200 pounds). Apparently, in these positions the thorax becomes fixed quickly during the act of pulling and remains so while further tension is applied to the ring.

The smaller amounts of intrathoracic pressure in the more flexed positions, as compared with those in the upright position, may be at least partially accounted for by the fact that in the upright position all the force on the strain ring is transmitted through the rib cage and thoracic part of the spine. In the flexed positions, however, the force on the strain ring is distributed from the arms by way of the trapezius and latissimus dorsi along the thoracic and even the lumbar portions of the spine. Therefore, since there is less total force transmitted through the thorax, there is less increase of intrathoracic pressure and less need for rigidity and fixation of the rib cage.

Effects of an Inflatable Corset

It has been observed for some time that, in cases of pain in the lower part of the back due to disc degeneration or so-called mechanical instability of the back, compression of the abdominal viscera often relieves the pain. This compression may be accomplished by a tight corset, a brace with an abdominal pad which can be tightened, or a snug plaster body jacket.

As part of the study of the support of the spinal column, an investigation of the effects of externally applied pressure and support for the trunk was begun. The first apparatus to be studied was a corset inflated to the limit of comfort. At

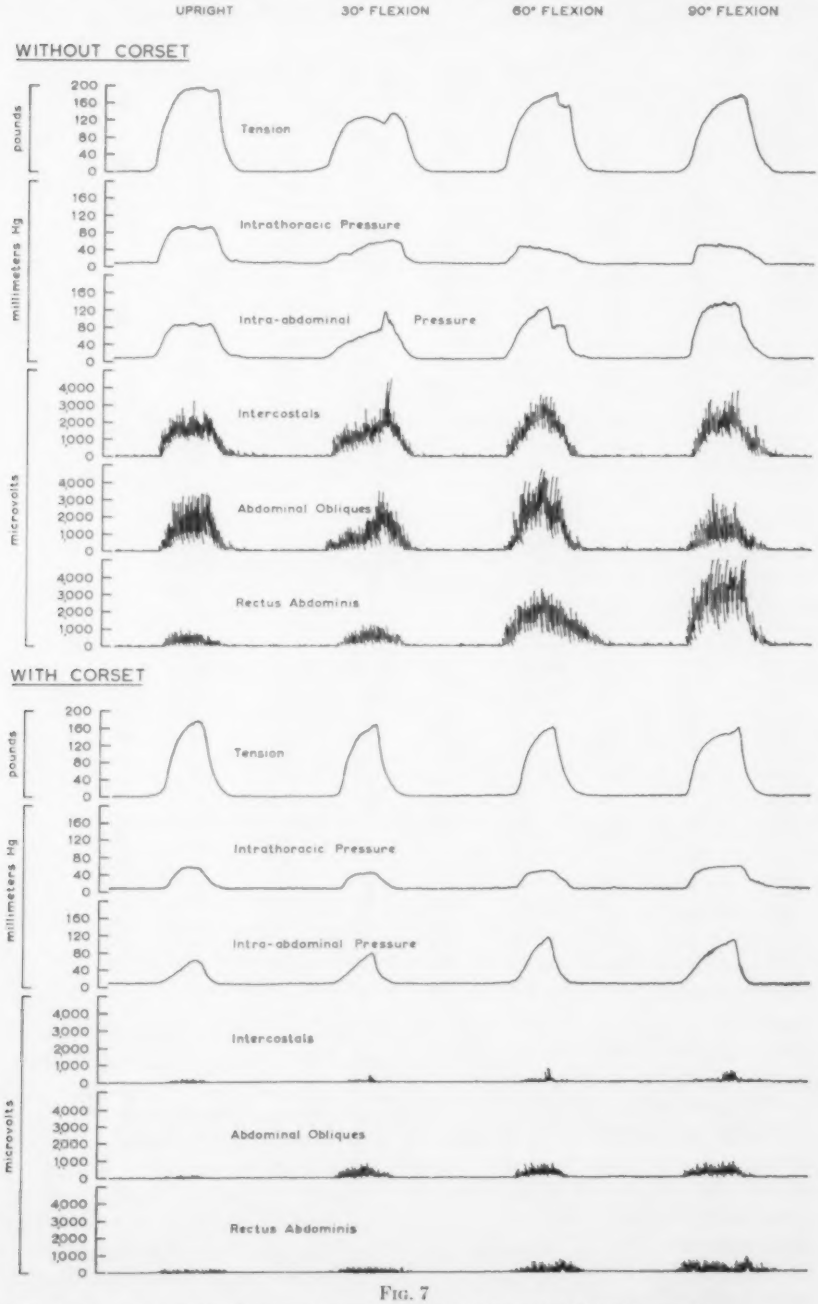

FIG. 7

Effect on muscle activity of external compression of abdomen by inflatable corset.

TABLE V

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE TO STATIC LOADING OF THE SPINE WITHOUT INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	204	50	120	60	114	80	136	84
MK	2	228	100	212	136	200	130	204	136
RD	1	90	24	114	56	132	136	124	108
RD	2	64	80	176	108	170	148	180	148
CC	1	140	42	112	32	116	44	86	40
CC	2	120	24	128	32	116	50	136	96
CC	3	188	56	204	60	170	100	136	100
CC	4	200	88	208	72	176	120	166	132
JM	1	200	88	174	120	196	128	194	136
JM	2	182	84	184	112	182	122	188	128
BS	1	136	40	124	50	122	86	120	74
BG	1	104	50	140	74	140	78	140	80
BG	2	128	44	136	58	146	72	168	94
BG	3	198	74	210	100	200	100	200	92
BG	4	202	96	188	96	188	124	176	90
BE	1	206	84	170	94	164	94	156	80

TABLE VI

RELATIONSHIP OF INTRATHORACIC PRESSURE TO STATIC LOADING OF THE SPINE WITHOUT INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	228	100	212	50	200	60	204	56
RD	1	90	32	114	50	132	72	124	70
RD	2	164	52	176	66	170	56	180	64
CC	1	140	50	112	28	116	44	86	48
CC	2	120	10	128	20	116	32	136	28
JM	1	200	88	174	44	196	42	194	44
JM	2	182	68	184	50	182	40	188	42
BS	1	136	30	124	30	122	44	120	40
BG	1	104	56	140	62	140	70	140	82
BG	2	128	48	136	48	146	72	168	84
BG	3	198	56	224	56	204	36	200	42
BG	4	202	62	188	40	188	50	176	36

this point there was no weakness or paresthesia of the lower limbs (such as would occur with an increase of the pressure), and there was a subjective feeling of rigidity and support of the trunk.

Eight experimental runs were carried out on six subjects, with certain significantly consistent results despite the small number. The resting abdominal pressure was elevated from five to eight millimeters of mercury to twenty to twenty-five millimeters of mercury. With normal inspiration there was an increase of five to ten millimeters of mercury in the abdominal pressure, and when the trunk was flexed an increased elevation of the pressure occurred because of the restraint given by the apparatus. The intrathoracic pressure was elevated only slightly, if at all.

TABLE VII

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE TO STATIC LOADING OF THE SPINE WITH INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	220	80	220	80	186	122	192	110
MK	2					200	120		
RD	1	184	92	140	100	170	110	168	100
CC	1	144	48	116	50	96	50	108	54
CC	2	160	56	180	90	176	120	152	96
JM	1	172	48	164	66	160	88	152	80
BS	1	154	68	156	88	148	96	96	80
BG	1	168	68	132	68	116	68	122	70
BG	2	220	128	210	114	200	124	196	116

TABLE VIII

RELATIONSHIP OF INTRATHORACIC PRESSURE TO STATIC LOADING OF THE SPINE WITH INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	228	70	240	72	186	80	192	50
RD	1	184	88	140	74	170	74	168	64
JM	1	172	40	164	42	160	44	152	52
BS	1	154	50	156	66	148	62	96	50
CC	1	144	56	116	54	96	60	108	48
BG	1	168	68	132	60	116	60	122	60
BG	2	220	56	216	60	200	54	196	48

It is interesting to note that, while the resting intra-abdominal pressure was considerably elevated by the corset, the maximum pressures generated in static loading of the spine were quite comparable to those obtained without the corset (compare Figs. 4 and 6). The slope of the lines indicating the relationship of the intra-abdominal pressure to the strain-ring tension (Fig. 6) was determined by the method of least squares. Because of the small amount of data, more observations might change the slopes of the lines in Figure 6. This possibility may account for the discrepancy in the slopes in Figures 4 and 6.

It would appear that there is little if any difference in the maximum pressures in the abdomen or thorax with and without the corset during static loading of the spine. The slightly lower pressures occasionally seen with the corset may be due to the fact that some of the force normally transmitted through the trunk is transmitted instead through the apparatus.

However, when the activity of the trunk muscles is compared during loading with and without the corset, a marked difference is obvious (Fig. 7). The activity of the abdominal obliques and the rectus abdominis is consistently and considerably decreased when the corset is worn, despite the fact that the intra-abdominal pressures may be the same. The intercostal activity was also noted to be decreased if the corset came high up on the chest over the intercostal muscles being

studied. In tall subjects, however, on whom the corset did not extend as high as on the shorter subjects, there was no effect on the intercostal activity.

CALCULATION OF ACTUAL FORCES ON THE SPINE

To illustrate the role of the trunk in the support of the spine, the data obtained experimentally may be used to calculate the approximate forces on the spine in the living human being when a weight of 200 pounds is lifted. Since by far the largest forces are imposed on the lumbar and lower thoracic regions, these will be considered, along with the effect of the intra-abdominal pressure.

The influence of the trunk muscles and the intra-abdominal pressure on the forces transmitted by the spine can be demonstrated by considering the static equilibrium of the upper part of the body. The forces which must be considered in

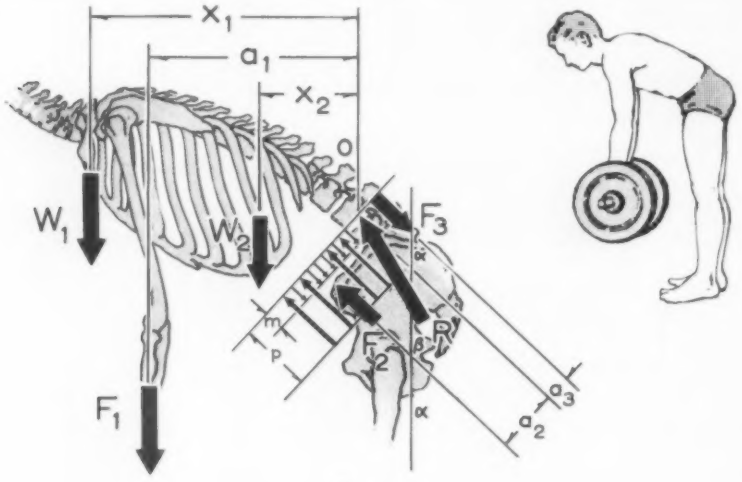

FIG. 8

Forces used in calculations.

this idealized system are (1) gravity forces—the body weight and any additional external weight carried by the body, (2) the tension in the deep muscles of the back and in the muscles of the abdominal wall, (3) the pressure (p) in the internal cavities of the trunk (intra-abdominal and intrathoracic), and (4) the force transmitted by the spinal column. The spinal column may be considered to act as a flexible segmental column, whereas the thoracic and abdominal cavities may be considered as inflatable structures contained within the trunk and restrained by the thoracic cage and abdominal muscles.

To determine the force on the spine at a given level, it is necessary to consider the external (gravity) forces acting on the body above this level and the internal forces resisting or supporting the external forces (Fig. 8). The external forces can be grouped together or divided into several components. For convenience, the weights of head, neck, and arms are grouped together for calculation as one force (W_1) and the weight of the torso above the given level is considered separately as another force (W_2); both act through their respective centers of gravity. The weight lifted by the arms is considered as a separate force (F_1) acting through its center of gravity.

The resisting internal forces are the net force of the intra-abdominal pressure and tension of the longitudinal component of the abdominal muscles (F_3), the

tension in the deep muscles of the back (F_3), and the reaction (R) on the spine at the given level. (Although the tension of the transverse component of the abdominal muscles contributes to the increase of abdominal pressure, it has little effect on the static equilibrium and therefore has been neglected in the following equations.)

The magnitudes of the forces W_1, W_2, and F_1 and their position in space relative to the disc 0 (Fig. 8), defined by distances x_1, x_2, and a_1, are known for a subject in a given posture and activity. For a given set of external forces, the magnitudes of the forces F_2, F_3, and R cannot be defined solely by considerations of equilibrium, since they depend on the activity of the abdominal muscles, the back muscles, and the intra-abdominal pressure. If the activity of the abdominal muscles in terms of developed tension forces and the intra-abdominal pressure are

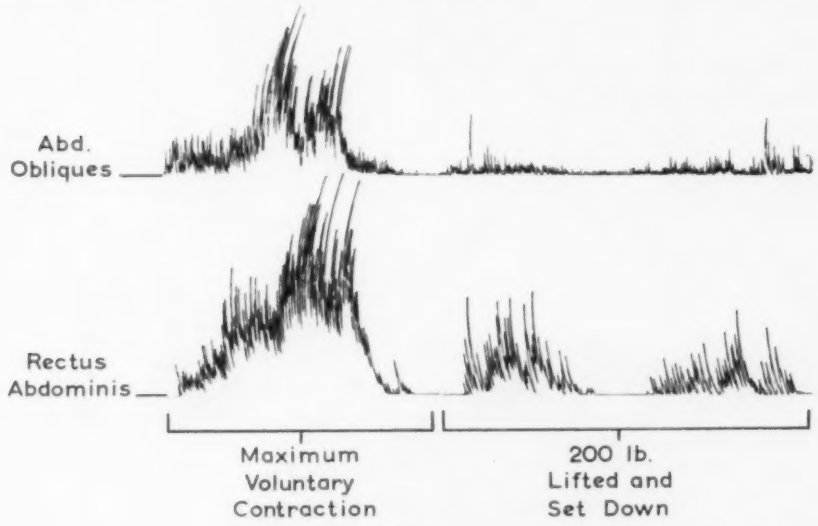

FIG. 9

Electromyographic activity during maximum voluntary contraction and during lifting.

measured, then the net resultant force F_2 can be determined. If p is the intensity of intra-abdominal pressure acting on an effective abdominal cross section, A_a, and m is the estimated intensity of longitudinal muscle tension on an effective muscle cross section A_m, then

$$F_2 = pA_a - mA_m \tag{1}$$

The remaining unknown forces F_3 and R can be calculated under conditions of static equilibrium. In most cases it is sufficient to assume that the net abdominal force F_2 and the tension in the back muscles F_3 are parallel, making an angle α with the vertical.

The tension in the back muscles (F_3) is an unknown. However, for static equilibrium, the sum of the moments about the fulcrum (0) must equal zero, or

$$W_1x_1 + W_2x_2 + F_1a_1 - F_2a_2 - F_3a_3 = 0$$

from which F_3 may be obtained:

$$F_3 = \frac{W_1x_1 + W_2x_2 + F_1a_1 - F_2a_2}{a_3} \tag{2}$$

The reaction (R) is of most interest in this study. Its magnitude and direction are unknown and may be determined in a similar way, by considering the

conditions of equilibrium. The resultant sum of forces acting at the fulcrum 0 must be zero (this includes R). This condition may now be divided into two parts:
(1) The sum of the vertical components of the forces must equal zero, or

$$W_1 + W_2 + F_1 - F_2 \cos \alpha + F_3 \cos \alpha - R \cos \beta = 0$$

from which

$$R \cos \beta = W_1 + W_2 + F_1 + (F_3 - F_2) \cos \alpha \quad (3)$$

(2) The sum of the horizontal components of the forces must equal zero, or

$$F_2 \sin \alpha - F_3 \sin \alpha + R \sin \beta = 0$$

or

$$R \sin \beta = (F_3 - F_2) \sin \alpha \quad (4)$$

Values of the reaction R and the angle β can be determined as follows: Dividing Equation 3 by Equation 2,

$$\frac{R \sin \beta}{R \cos \beta} = \tan \beta = \frac{(F_3 - F_2) \sin \alpha}{W_1 + W_2 + F_1 + (F_3 - F_2) \cos \alpha} \quad (5)$$

Solving for tan β, and hence β, from Equation 5, the magnitude of the force R can be calculated from Equation 4:

$$R = \frac{(F_3 - F_2) \sin \alpha}{\sin \beta} \quad (6)$$

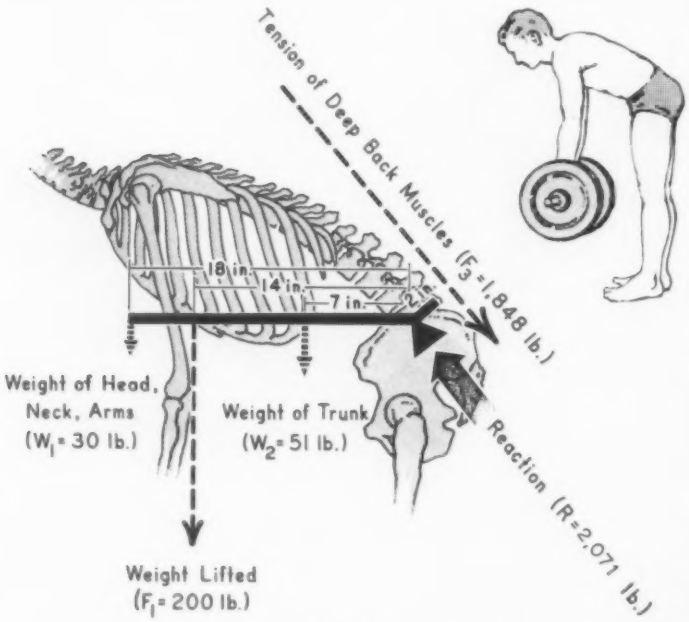
Tension of Deep Back Muscles (F_3 = 1,848 lb.)
18 in.
14 in.
7 in.
Weight of Head, Neck, Arms (W_1 = 30 lb.)
Weight of Trunk (W_2 = 51 lb.)
Reaction (R = 2,071 lb.)
Weight Lifted (F_1 = 200 lb.)

FIG. 10

Force on lower lumbar part of spine, omitting role of trunk.

With use of the equations thus derived, the force at the base (lumbosacral junction) of the spine can be determined.

With knowledge of the amount of weight lifted, the body weight, the reaction to the intra-abdominal pressure, and the distances from the lumbosacral disc or fulcrum at which the forces act, the tension of the deep back muscles can be calculated. When all the forces and their directions are known, the reaction at the lumbosacral disc can be determined (see Appendix 2). Thus, instead of a force to

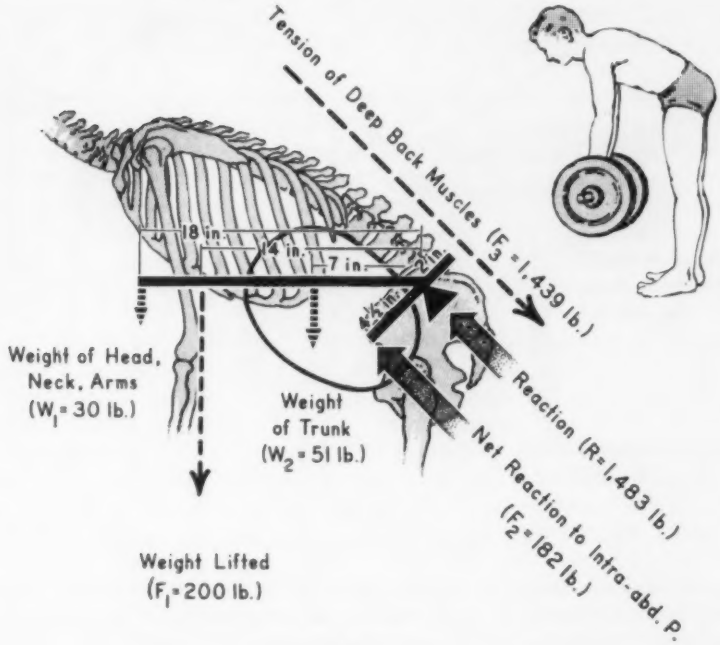
Tension of Deep Back Muscles (F_3 = 1,439 lb.)
18 in.
4 in.
7 in.
Weight of Head, Neck, Arms (W_1 = 30 lb.)
Weight of Trunk (W_2 = 51 lb.)
Reaction (R = 1,483 lb.)
Net Reaction to Intra-abd. P. (F_2 = 182 lb.)
Weight Lifted (F_1 = 200 lb.)

FIG. 11

Force on lower lumbar part of spine, including role of trunk.

2,071 pounds (Fig. 11) at the base of the beam, there is, because of the "inflatable support", a force of only 1,483 pounds—a reduction of 600 pounds.

Next, the force on the lower thoracic part of the spine can be calculated, again with the example of a weight of 200 pounds being lifted in the flexed position.

The total force acting on the diaphragm can be calculated by multiplying the area of the diaphragm by the intra-abdominal pressure. This upward force is partially counteracted, however, by the downward pull on the rib cage by the longitudinal components of the abdominal-wall muscles during compression of the viscera (see Appendix 1 for calculation).

When the spine is heavily loaded, the diaphragm contracts and becomes relatively flattened and rigid. It may be thought of as a lever attached to the lower thoracic vertebrae through the ribs and to the upper three lumbar vertebrae by means of the crura. If the upward force is assumed to act at the center of the diaphragm, the ratio between the diaphragmatic lever (distance from center of diaphragm to fulcrum, which for practical purposes is assumed to be the center of the nucleus pulposus of the disc between the tenth and eleventh thoracic vertebrae) and the posterior lever acted on by the deep back muscles (distance from mid-point of spinous process to fulcrum) is approximately four to one. The upward force is transformed through the lever system into a force about four times larger acting in the same direction as the contraction of the deep muscles of the back and forming a force couple with the tension developed in these muscles.

If the role of thorax and abdomen is ignored, the force on the lower thoracic region of the spine may be calculated as it was for that at the base of the spine, except that the lever arm acted on by the weight lifted is considerably shorter than the lever arm at the base of the spine and that the posterior lever is also

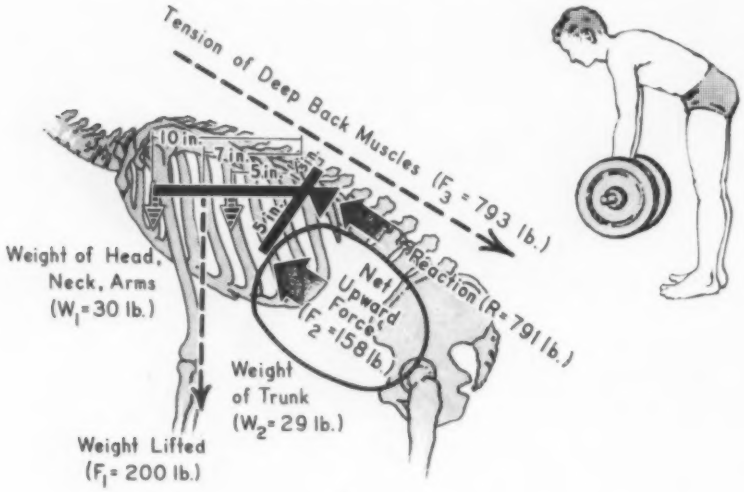
Tension of Deep Back Muscles (F_3 = 793 lb.)
10 in.
7 in.
5 in.
5 in.
Weight of Head, Neck, Arms (W_1 = 30 lb.)
Net Upward Force (F_2 = 158 lb.)
Reaction (R = 791 lb.)
Weight of Trunk (W_2 = 29 lb.)
Weight Lifted (F_1 = 200 lb.)

FIG. 12

Force on lower thoracic part of spine, including role of trunk.

somewhat shorter. The force on this region of the spine thus obtained is 1,568 pounds. By the relatively simple mechanism of an upward push on the diaphragm by increased intra-abdominal pressure, the force on the lower thoracic and upper lumbar vertebrae and discs is reduced to 791 pounds (Appendix 2).

CONCLUSIONS

There is a great discrepancy between the force that can theoretically be applied to the spine if the role of intracavitary pressures is ignored and the force that can be tolerated experimentally by the isolated ligamentous human spine.

In estimating that a force of approximately 2,071 pounds is imposed on the lower lumbar part of the spine when a weight of 200 pounds is lifted in the flexed position, the vertebral column is considered only as an isolated unit being acted on by the forces of the weight lifted, the body weight, and the contraction of the deep muscles of the back. Such a picture, however, is quite simplified, since no account is taken of the important role of the trunk—thorax and abdomen—in support of the spine. ("Support" is used here in its broadest sense, meaning maintenance of stability of the column against deformity and against structural damage of its components.) The answer to the question of how the vertebral column in a living subject is able to withstand a far greater force than the isolated column must be found by consideration of the extrinsic supporting structures of the trunk.

In this study, data on the mechanism of support of the spine by the trunk have substantiated the hypothesis made at the beginning of the study: The spinal column is attached to the sides of and within two chambers, the abdominal and thoracic cavities; the action of the trunk muscles converts these chambers into nearly rigid-walled cylinders containing (1) air and (2) liquid and semisolid material. Both these cylinders are capable of transmitting part of the forces generated in loading the trunk and thereby of relieving the load on the spine itself.

When large forces are applied to the spine—for example, lifting weights of 100 to 200 pounds—there is generalized contraction of the trunk muscles, including the intercostals, the muscles of the abdominal wall, and the diaphragm. The

muscles about the shoulder girdle and those of the back are, of course, active during lifting, just as the muscles of the thighs help maintain body balance and the erect position.

The action of the intercostals and of the muscles of the shoulder girdle renders the thoracic cage a quite rigid structure firmly bound to the thoracic part of the spine. When inspiration and the action of the intercostal muscles, which stabilize the rib cage, increase intrathoracic pressure, the thoracic cage and spine become a solid, sturdy unit capable of transmitting large forces. By the contraction of the diaphragm, attached at the lower margin of the thorax and overlying the abdominal viscera, and of the muscles of the abdominal wall, especially the transversus abdominis, the abdominal contents are compressed into a semirigid cylinder.

The force of weights lifted by the arms is thus transmitted to the spinal column by the shoulder-girdle muscles, principally the trapezius, and then to the abdominal cylinder and to the pelvis, partly through the spinal column but also through the rigid rib cage.

When larger forces are involved, there is need for increased rigidity of the rib cage and compression of the abdominal contents. This accounts for the increased activity of the trunk muscles and the increase in intracavitary pressures when greater forces are applied. Thus, an increased intra-abdominal pressure is due to the contraction of the abdominal muscles and to the compression of the abdomen by the force which is transmitted through the trunk.

This view is well substantiated by the fact that when an air-pressure corset is worn, although the resting abdominal pressure is considerably elevated (by approximately twenty millimeters of mercury), the pressures recorded during loading of the spine are similar to those recorded without the corset. However, the activity of the abdominal muscles is markedly decreased when the inflatable corset is worn. It appears, therefore, that the contracted muscles of the abdominal wall or the rigid external-pressure apparatus act to contain the abdominal contents in a compressed state capable of transmitting force. When the compression or restraint is accomplished by an external apparatus, there is little need for contraction of the abdominal muscles. However, a small amount of activity is noted in the abdominal muscles even when the corset is worn, especially when greater forces or heavier loads are applied. The amount of compression of the viscera necessary to transmit these great forces can be tolerated briefly but not for prolonged periods. Since, in this study, the apparatus was inflated to the limit of comfort for extended periods, the abdomen was not compressed enough to obviate entirely the need for muscle activity with the larger forces.

It should be emphasized that the mechanism discussed here is a reflex mechanism. When a load is placed on the spine, the trunk muscles are involuntarily called into action to fix the rib cage and to restrain or compress the abdominal contents. The intracavitary pressures are thereby increased, aiding in support of the spine.

It may be concluded, from this calculation of the contribution of the trunk compartments to the support of the spine, that the actual force on the spine is much less than that considered to be present when support by the trunk, or the effect of the intracavitary pressures, is omitted. The calculated force on the lumbosacral disc is about 30 per cent less, and that on the lower thoracic portion of the spine is about 50 per cent less, than would be present without support by the trunk.

These particular results are applicable under the conditions described in this report—near-maximum loading of the trunk (lifting a 200-pound weight) in the

flexed position. However, with appropriate consideration of the surrounding structures, the position of the spine, and the forces acting at a specific level, the general principles illustrated by this investigation can be used to determine the force at any level of the spine under a variety of situations.

APPENDIX 1

The approximate value of the longitudinal component of the tension of the abdominal muscles was calculated as follows:

The cross-sectional areas of the abdominal obliques and the recti were determined with values obtained from Weber's tables [8].

	Longest fibers (*centimeters*)	Weight (*grams*)
Rectus abdominis	29.7	131.65
External oblique	18.4	115.05
Internal oblique	12.4	107.12

The following formula was used:

$$\text{Cross section} = \frac{W}{\rho L} = \frac{V}{L}$$

where

W = weight in grams

ρ = density of muscle (1.06 grams per cubic centimeter)

L = length of muscle (longest fibers) in centimeters

V = volume in cubic centimeters

The values thus obtained were as follows:

Rectus abdominis 4.2 square centimeters

External oblique 5.9 square centimeters

Internal oblique 8.2 square centimeters

Since only the longitudinal component of these muscles is active in holding the rib cage down, this component was arrived at by considering the two oblique muscles as fan-shaped with some fibers running transversely, some longitudinally, and some obliquely. For ease of calculation, a mean obliquity of 45 degrees to the longitudinal was assumed for the fibers of each muscle as a whole. One-half of the cross section was assumed to act in the transverse direction and one-half in the longitudinal direction. The rectus abdominis, of course, acts only in the longitudinal direction.

The cross-sectional area of the abdominal-wall muscles acting in a longitudinal direction was calculated as follows:

Rectus abdominis (both sides): 4.2 square centimeters $\times$ 2 = 8.4 square centimeters

External oblique (longitudinal component): 5.9 square centimeters $\times$ ½ $\times$ 2 = 5.9 square centimeters

Internal oblique (longitudinal component): 8.2 square centimeters $\times$ ½ $\times$ 2 = 8.2 square centimeters

Total cross-sectional area acting in a longitudinal direction = 22.5 square centimeters

On the basis of the value four kilograms per square centimeter [4], the maximum voluntary longitudinal force which could theoretically be produced by this muscle mass is ninety kilograms (198 pounds).

Since these muscles were not maximally active during the weight lifting, an attempt was made to determine the degree of activity by comparing electro-

myographic activity during maximum voluntary contraction and during the act of lifting. The position in which the voluntary contraction was performed was the same as that in lifting the weights. Isometric contractions were also compared, with the strain ring used as the method of loading.

The results were similar and are illustrated in Figure 9.

As can be seen, the degree of activity in the abdominal obliques during loading is approximately one-sixth of that obtained with maximum voluntary contraction. The activity of the rectus abdominis with loading is somewhat less than one-half of the maximum voluntary activity.

The maximum longitudinal force which can theoretically be generated by the abdominal obliques is the cross-sectional area of the longitudinal components of the muscles, 14.1 square centimeters, multiplied by four kilograms per square centimeter or 56.4 kilograms. However, when the muscles function at only one-sixth of their maximum, the longitudinal force is only 9.4 kilograms. Similarly, the force produced by the rectus abdominis is calculated by multiplying the area 8.4 square centimeters by four kilograms per square centimeter and dividing by two (degree of activity), which equals 16.8 kilograms. The total longitudinal force generated by the obliques and the rectus abdominis while lifting 200 pounds is therefore 26.2 kilograms or 57.64 pounds.

APPENDIX 2

Force on Lumbosacral Disc

In determination of the reaction of force at the lumbosacral disc, to be considered are the weight lifted (F_1), the reaction of the pelvis to the net downward force of the intra-abdominal pressure (F_2), the tension of the deep muscles of the back (F_3), and the body weight as divided into two parts (W_1 and W_2).

Omission of Intracavitary Pressures: In this calculation, which is illustrated in Figure 10, the reaction of the pelvis to the net downward force of the intra-abdominal pressure is omitted.

Let M_1 denote the moment resulting from a force of 200 pounds acting at 14 inches (the distance, in a subject flexing his spine to lift the weight, from the arm to the center of the fifth lumbar disc); then $M_1 = 2{,}800$ pound-inches.

Let M_4 denote the moment resulting from the body weight. Body weight has been divided into two parts: W_1 and W_2. W_1 (head, neck, and arms) is thirty pounds (17.7 per cent of the total body weight) and acts at a distance of eighteen inches from the fulcrum. W_2 (the weight of that part of the trunk above the lumbosacral disc) is fifty-one pounds (30 per cent of the total body weight) and acts seven inches from the fulcrum. Addition of the moments of these two components of body weight gives $M_4 = (30 \text{ pounds} \times 18 \text{ inches}) + (51 \text{ pounds} \times 7 \text{ inches}) = 897$ pound-inches.

The force exerted by the back muscles (F_3) is treated as an unknown, as in the reaction (R) of the pelvis to the net resultant of forces acting on the spine at the lumbosacral junction.

For static equilibrium, $\Sigma M = 0$. With use of this fact, F_3 may be solved for (with M_3 being the moment of this force acting at 2 inches—the distance from the center of the lumbosacral disc to the mid-point of the spinous process of the fifth lumbar vertebra, the level at which most of the deep muscles of the back are attached).

M_1 and M_4 are negative by convention. Transposing and substituting known values,

$$F_3 = \frac{2{,}800 \text{ pound-inches} + 897 \text{ pound-inches}}{2 \text{ inches}} = 1{,}848.5 \text{ pounds}$$

Further, the resultant sum of the forces acting at 0 (lumbosacral disc) must be in equilibrium with the reaction (R). This condition may be conveniently expressed as follows: The resultant sum of the forces acting at 0 should be zero. (Note that this includes R.) This condition may be divided into two parts: The sum of the vertical components of forces at 0 should be zero, and the sum of horizontal components of forces at 0 should also be zero. Then, algebraically, the conditions are as follows:

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - R \cos \beta = 0$

Angle β is an unknown. Angle α is assumed to be 40 degrees. Substituting known values, 200 pounds + 30 pounds + 51 pounds + 1,848.5 cos 40° = R cos β. R cos β = 1,697 pounds.

R sin β = 1,189 pounds. .574 R = 1,189 pounds. R = 2,071 pounds

Inclusion of Intracavitary Pressures (Fig. 11): M_1 is calculated, as just noted, to be 2,800 pound-inches. Let M_2 denote the moment resulting from the reaction of the pelvis to the downward force of the intra-abdominal pressure. Since the maximum pressure is 148 millimeters of mercury, or three pounds per square inch, and the cross-sectional area may be estimated at eighty square inches, the force exerted on the pelvis is 240 pounds. The net downward force is obtained by subtracting the tension of the vertical components of the abdominal muscles, fifty-eight pounds (Appendix 1), which gives 182 pounds. The equal and opposite reaction force of the pelvis (F_2) = 182 pounds. It may be considered to act 4.5 inches from the center of the disc, or approximately at the center of the abdominal cavity. Therefore, M_2 = 819 pound-inches (182 pounds × 4.5 inches). $M_3 = F_3$ (an unknown) × 2 inches (its lever arm). M_4 is calculated, as before, to be 897 pound-inches. It may be assumed that the connection between pelvis and spine can be approximated by a universal joint and that F_2 and F_3, acting in opposite directions, are parallel in a direction (angle α) 40 degrees to the vertical.

$\Sigma M = 0$

$F_3 \times 2 \text{ inches} = -(M_1 + M_2 + M_4)$

$$F_3 = \frac{-(-2{,}800 \text{ pound-inches} + 819 \text{ pound-inches} - 897 \text{ pound-inches})}{2 \text{ inches}}$$

F_3 = 1,439 pounds

In order to obtain the reaction (R) at point 0, the vertical and horizontal components of the forces acting on this point are considered:

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - F_2 \cos \alpha - R \cos \beta = 0$

Horizontal components: $F_3 \sin \alpha - F_2 \sin \alpha - R \sin \beta = 0$

$$\tan \beta = \frac{R \sin \beta}{R \cos \beta}$$

Angle β, which the reaction (R) makes with the vertical direction, and the magnitude of R are not known, but with the values for F_1, F_2, F_3, W_1, W_2, and angle α (40 degrees) the equations just given can be used to obtain the two unknowns.

Solving for R and angle β, the force on the lumbosacral disc is found to be 1,483 pounds, which, in this specific example, acts in a direction 33 degrees to the vertical.

Force on Lower Thoracic Portion of Spine

The force on the lower thoracic part of the spine may be calculated by the same method. In the same specific example, the reaction (R), or the force at the disc between the tenth and eleventh thoracic vertebrae (point 0), will be determined. The spine at this level will be assumed to form an angle α of 60 degrees to the vertical.

F_1 is the weight of 200 pounds acting at a distance of seven inches from point 0. F_2 is the net upward force on the diaphragm—158 pounds acting five inches from 0. F_3 is the tension of the deep muscles of the back acting on the short posterior lever arm one and one-third inches from point 0. W_1 is thirty pounds (the weight of the head, neck, and arms) acting ten inches from the fulcrum, and W_2 is twenty-nine pounds (the weight of the trunk above the disc between the tenth and eleventh thoracic vertebrae) acting five inches from the fulcrum. The moments of these components are added to obtain M_4 (the moment of the body weight), which thus = 445 pound-inches.

Omission of Intracavitary Pressures: F_3 is calculated by use of the equation $\Sigma M = 0$, or

$$F_3 = \frac{M_1 + M_4}{1\frac{1}{3} \text{ inches}} = \frac{1{,}845 \text{ pound-inches}}{1\frac{1}{3} \text{ inches}} = 1{,}387 \text{ pounds}$$

In order to determine the reaction (R) at point 0, the vertical and horizontal components of the forces acting on this point are again considered.

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - R \cos \beta = 0$

Horizontal components: $F_3 \sin \alpha - R \sin \beta = 0$

$$\tan \beta = \frac{R \sin \beta}{R \cos \beta}$$

Solving for R and angle β, it is found that the force on the disc between the tenth and eleventh thoracic vertebrae is 1,568 pounds acting at an angle of approximately 50 degrees to the vertical.

Inclusion of Intracavitary Pressures (*Fig. 12*): Solving for F_3, $\Sigma M = 0$

$M_1 + M_2 + M_3 + M_4 = 0$, or

$-$ (200 pounds $\times$ 7 inches) + (158 pounds $\times$ 5 inches) + ($F_3 \times 1\frac{1}{3}$ inches)

$-$ (30 pounds $\times$ 10 inches + 29 pounds $\times$ 5 inches) = 0

$$F_3 = \frac{1{,}400 \text{ pound-inches} - 790 \text{ pound-inches} + 445 \text{ pound-inches}}{1\frac{1}{3} \text{ inches}} = 793 \text{ pounds}$$

In determination of R, the vertical and horizontal components of the forces are again considered.

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - F_2 \cos \alpha - R \cos \beta = 0$

Horizontal components: $F_3 \sin \alpha - F_2 \sin \alpha - R \sin \beta = 0$

$$\tan \beta = \frac{R \sin \beta}{R \cos \beta}$$

Solving for R and sin β in these equations, it is found that the actual force on this disc is 791 pounds acting at approximately 44 degrees to the vertical.

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Cellular Response to Fracture Studied with Tritiated Thymidine*

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When Bier, Ham [6], and Ham and Harris [7] published their comprehensive histological studies of fracture repair, methods for determination of the proliferative potentials of cells and the temporal relationship of their proliferative response to traumatic stimuli were not available. It has never been questioned that wound repair involves cellular proliferation. However, the identification of the cell type while the cell is in mitosis and the transformation of a mitotic cell of one type into other cell types can only be deduced if the precursor cells can be identified by a permanent tag that labels these cells during subsequent transformations. Tritium-labeled thymidine specifically labels desoxyribonucleic acid during the period of chromosomal replication. The label is non-exchangeable and is reduced in intensity only by cell division. The presence of this label is easily determined by autoradiographic methods [2,3,4,5,8,9].

The object of this investigation was to estimate the cellular response to fracture and to study the subsequent transformation of cells from initial proliferation throughout the process of fracture repair.

These studies supplement earlier ones on the use of tritiated thymidine during bone growth, aging, and repair [17,19].

MATERIALS AND METHODS

Forty-two female Swiss albino mice of the Brookhaven National Laboratory strain, five weeks of age, were used in the experiments. With the mice under ether anesthesia, the right femur of each animal was fractured in the mid-diaphyseal region by digital pressure. The left femur served as a control. Tritiated thymidine (H^3TDR) was administered to the mice subcutaneously in a dose of 0.5 microcurie per gram of body weight (Sp. Ac. 1.9c/mM) one hour before killing. The animals were killed at one, two, four, eight, sixteen, twenty-four, and thirty-two hours at two, three, four, five, seven, ten, and fourteen days after fracture.

Tissue samples were fixed for three hours in acetic acid and alcohol, then for twenty-four hours in formaldehyde-saline solution, and then washed for an additional twenty-four hours in running tap water. Bones were decalcified in a 10 per cent solution of disodium versenate and embedded in paraffin. Sections five micra thick were mounted †, dipped in liquid emulsion, dried, and exposed for twenty days in a cold, dry atmosphere. The autoradiographic preparations were stained with hematoxylin and eosin.

The cellular population of the osteogenic layer of the periosteum was studied in particular at different time intervals in both fractured and non-fractured femora. To avoid confusion in terminology, the following terms as used in the present investigation are defined: *osteogenic cells* refers to those cells which take part in osteogenesis (pre-osteoblasts and osteoblasts). *Pre-osteoblasts* are progenitor cells which give rise to osteoblasts. *Osteoblasts* are cells which form the osseous matrix.

* Research supported by the United States Atomic Energy Commission.

† NTB_3 Eastman Kodak, Rochester, New York.

TABLE I

INCIDENCE OF SUBCORTICAL ENDOSTEAL * CELLS LABELED WITH TRITIATED THYMIDINE IN MOUSE FEMORA WITH AND WITHOUT FRACTURE

Time after Fracture:	Hours							Days						
	1	2	4	8	16	24	32	2	3	4	5	7	10	14
Control femora														
Labeling index †	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of cells counted	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	918	766	670	654
Fractured femora														
Labeling index †	0	0	.004	.001	.002	.01	.004	.006	.002	0	0	0	.002	0
Number of cells counted	600	1,000	500	1,000	600	800	500	611	530	947	1,000	693	389	413

* Endosteum lining trabecular bone was not included in the analysis.
† The labeling index, expressed as per cent, is the ratio of labeled cells to the total observed population of that cell.

The number of tritium-labeled cells in the observable population of pre-osteoblasts was counted. The labeling index, expressed as per cent, is the ratio of labeled cells to the total observed population of that cell.

Interpretation of tritiated thymidine autoradiographic data was based on previous reports from this laboratory [2,3,4,5,8,9,12].

RESULTS

Control Femora

In the periosteum of the normal femoral diaphysis of mice five weeks of age a maximum of 2 per cent of the cells of the osteogenic layer was labeled with tritiated thymidine. The cells of the osteogenic layer in the perichondrial regions near the epiphyses are excluded from this figure because of a higher labeling index

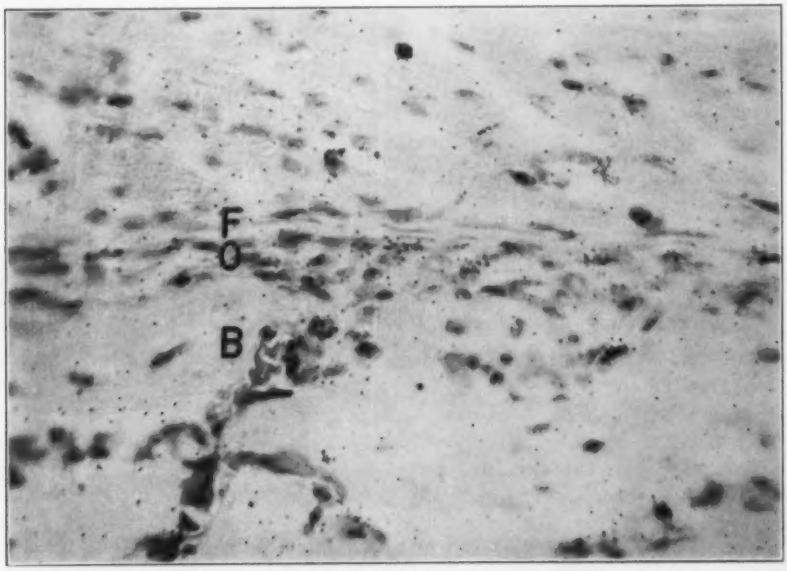

FIG. 1

An autoradiograph of a control femoral periosteum. Isotope uptake is shown by a number of labeled periosteal cells. Note the sparse labeling of the tissue at this time. *F* denotes the fibrous layer of the periosteum; *O*, the osteogenic layer; and *B*, the cortical bone (hematoxylin, × 350, oil immersion).

TABLE II

INCIDENCE OF PERIOSTEAL CELLS LABELED WITH TRITIATED THYMIDINE IN MOUSE FEMORA WITH AND WITHOUT FRACTURE *

	Hours after Fracture							
	1	2	4	8	16	24	32	48
Control femora								
Labeling index †	.018	.011	.025	.019	.015	.008	.023	.020
Number of cells counted	2,000	2,435	2,000	2,287	1,939	1,962	2,169	2,075
Fractured femora								
Labeling index †	.012	.014	.025	.011	.115	.173	.254	.212
Number of cells counted	2,107	2,055	2,030	1,940	2,436	2,499	2,713	3,814

* Table II is calculated in hours (1 to 48); Table III, in days (3 to 14).
† The labeling index, expressed as per cent, is the ratio of labeled cells to the total observed population of that cell.

TABLE III

INCIDENCE OF PERIOSTEAL CELLS LABELED WITH TRITIATED THYMIDINE IN MOUSE FEMORA WITH AND WITHOUT FRACTURE *

	Days after Fracture					
	3	4	5	7	10	14
Control femora						
Labeling index †	.029	.012	.021	.022	.019	.022
Number of cells counted	2,000	2,400	2,400	2,350	2,550	2,500
Fractured femora						
Periosteum over fracture areas:						
Labeling index †	.214	.098	.150	.090	.084	.065
Number of cells counted	2,700	2,000	1,121	1,800	2,240	1,650
Periosteum away from fracture areas:						
Labeling index †	.069	.033	.018	.019	.011	.014
Number of cells counted	900	2,000	2,220	1,569	2,350	2,300
Periosteum over and away from fracture areas:						
Labeling index †	.178	.065	.061	.059	.047	.036
Number of cells counted	3,600	4,000	3,341	3,369	4,590	3,950

* Table III is calculated in days (3 to 14); Table II, in hours (1 to 48).
† The labeling index, expressed as per cent, is the ratio of labeled cells to the total observed population of that cell.

in this region. In the periosteum, pre-osteoblasts are more frequently labeled than osteoblasts or fibroblasts (Fig. 1). Labeled osteocytes were not observed. In an earlier study [19], labeled osteocytes were not found as long as twenty-five days after administration of tritiated thymidine. Labeled subcortical endosteal osteoblasts (Table I and Fig. 2) were not observed. Extensive labeling of intertrabecular osteogenic cells and osteoblasts lining the trabeculae was seen especially in the metaphyseal regions. The *endosteum* usually refers to all cells which line the medullary canal. Since a significant difference in thymidine uptake was observed in this study between cells lining the diaphyseal cortex and those lining the trabeculae, the terms *subcortical* and *trabecular* endosteum were introduced for clarification. During the entire period of study, labeling of the periosteum of the control leg remained quite constant (Tables II and III and Chart I).

Fractured Femora

At sixteen hours after fracture, there was significant increase in labeling, indicating that between eight hours (the previous observations) and sixteen hours,

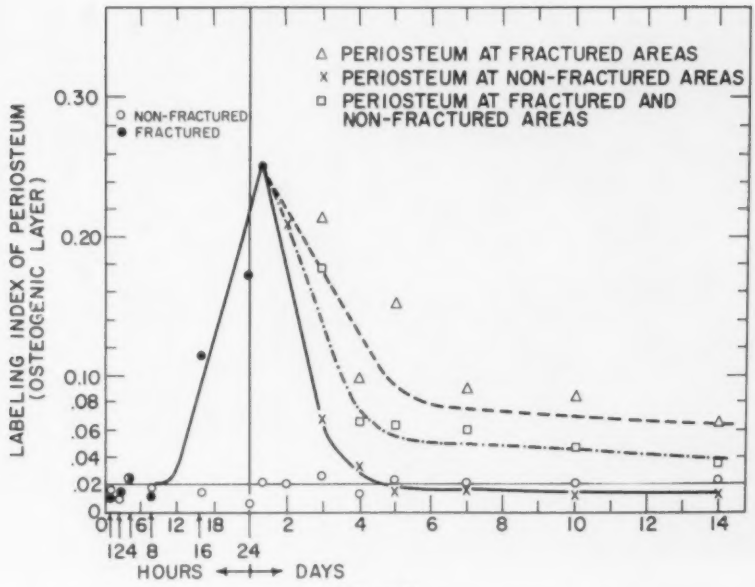

CHART I

The graph represents the labeling index of the periosteum of fractured and non-fractured femora, plotted against the time after fracture. Initially, the increased labeling is observed throughout the periosteum of the entire femoral shaft, although the fracture may be at mid-shaft. Increased labeling is seen up to thirty-two hours after fracture. During the ensuing time periods, the periosteal reaction subsides rapidly at first, then more gradually. However, the periosteal labeling away from the fractured area diminishes more rapidly than at the fractured area. Within five days the generalized periosteal response has reached the control levels while active repair is still going on about the fracture. At fourteen days the labeling is still elevated about the fracture, indicating active repair.

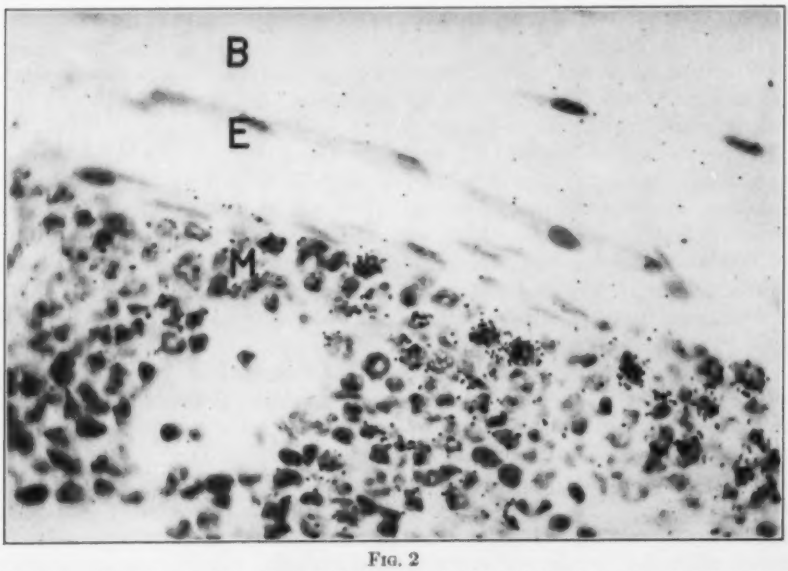

FIG. 2

An autoradiograph, one hour after administration of tritiated thymidine, showing abundantly labeled bone-marrow cells, *M;* non-labeled subcortical endosteal cells, *E;* and bone, *B*. The section was taken from a non-fractured femur (hematoxylin, × 585, oil immersion).

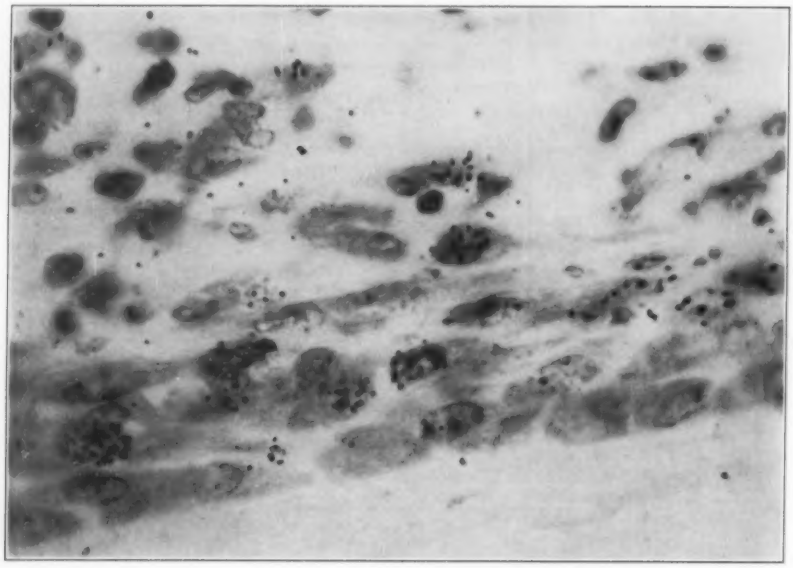

FIG. 3

The autoradiograph reveals the increased labeling of periosteal cells observed sixteen hours after fracture. Note that the labeling is generally distributed among pre-osteoblasts and mesenchymal cells outside the periosteum (hematoxylin, × 585, oil immersion).

cell proliferation had been stimulated by some factor associated with the fracture (compare Figs. 1 and 3). At this time interval, cell proliferation, as manifested by initiation of desoxyribonucleic-acid synthesis, was concentrated in pre-osteoblasts of the periosteum and in mesenchymal cells surrounding the periosteum (Fig. 3). With increasing time, proliferation of osteoblasts and fibroblasts began, as evidenced by labeling of these cells at later intervals (Fig. 4). Thirty-two hours after fracture, labeling of the periosteal-cell population increased to a maximum of 25.4 per cent. The labeling index of the periosteum up to forty-eight hours after fracture is presented in Table II.

It is curious that labeled cells were found throughout the diaphyseal periosteum, indicating that proliferation had been stimulated throughout the diaphyseal periosteum and was not limited exclusively to the fracture site. Relatively little increase in labeling of the subcortical endosteum was found throughout the study; the maximum labeling was approximately .01 per cent twenty-four hours after fracture (Table I). The periosteum and subcortical endosteum were missing for some distance from the fracture site and necrosis of osteocytes in the bone close to the fracture was observed.

In addition to proliferation of cells in the periosteum, numerous labeled mesenchymal-like cells were found between adjacent muscle fibers and in the hemorrhagic exudate. These cells were scattered along the entire length of the shaft, being more abundant around the fracture site (Fig. 5).

The distribution of labeled periosteal cells commenced to change thirty-two hours after fracture. In areas remote from the fracture, the labeling index commenced to decrease rapidly. A less rapid decrease in labeling index occurred in the area of callus. By five days after fracture, the labeling index in the areas remote from the fracture had decreased to the control level. In contrast to this, the labeling index of cells at the fracture site remained significantly higher than the control

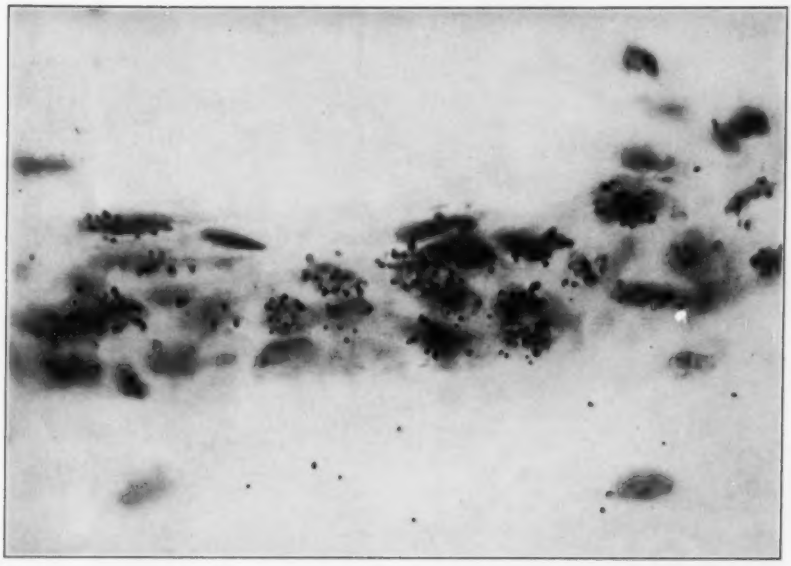

FIG. 4

The photomicrograph shows a section similar to Fig. 3; however, the autoradiograph was prepared thirty-two hours after a fracture. Note that the periosteum is abundantly labeled. At this time, numerous osteoblasts are labeled (hematoxylin, × 585, oil immersion).

level, even after fourteen days (Chart I and Table III). In addition, intense labeling of diverse cells was observed in the region of callus formation and in the portions of the callus where cartilage was being replaced by bone, as well as in the

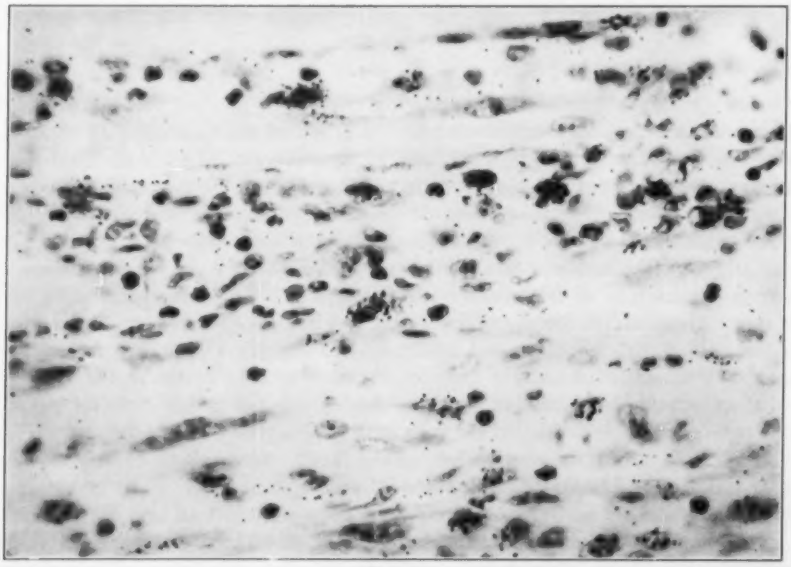

FIG. 5

Labeled osteogenic cells of the periosteum can be seen at the lower part of the photomicrograph. The typical cellular and fluid infiltration of adjacent muscle and connective tissue is seen above the periosteum. Note the abundance of highly labeled mesenchymal cells. The autoradiographic preparation was made thirty-two hours after fracture (hematoxylin, × 350, oil immersion).

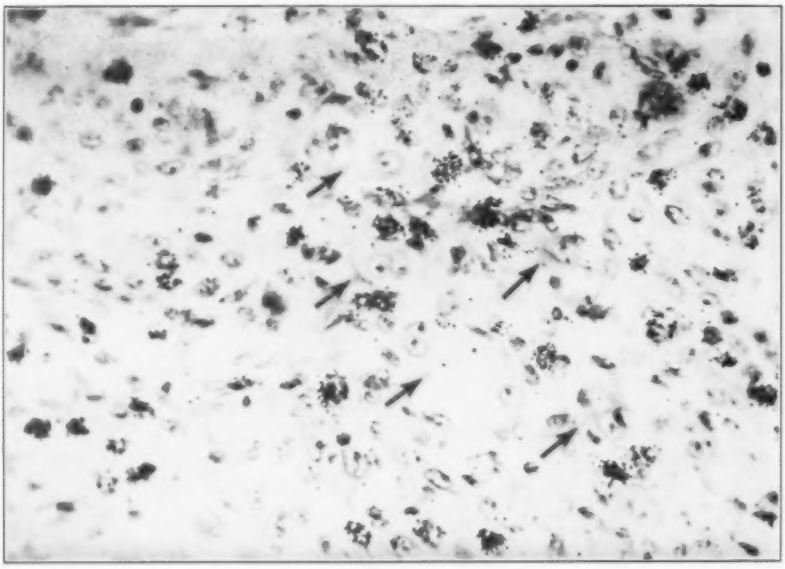

FIG. 6

This autoradiograph was prepared four days after fracture from a region where numerous osteogenic cells are in the process of callus formation. These cells are highly labeled. Note (arrows) the incorporation of degenerating muscle fibers within the cellular mass (hematoxylin, × 235, oil immersion).

sites of new-bone formation. The labeling of the cells at these sites continued until the process of fracture repair was complete (Figs. 6 and 7).

DISCUSSION

Tritiated Thymidine

Autoradiographic methods employing tritium as a label provide the high resolution necessary to establish the site of origin of the radioactivity in tissue by optical methods. Tritium has a maximum beta energy of 6.8 kilo electron volts. The average path length is one micron in tissue and the resolving power is approximately one micron [13]. If the radioactivity is concentrated in the nucleus, it can easily be detected optically. Thymidine (thymine desoxyriboside) labeled with tritium (H^3TDR) localizes in the nucleus because it is a specific precursor of desoxyribonucleic acid, thus combining the desirable properties of tritium with cytological localization. Tritiated thymidine is either incorporated into desoxyribonucleic acid during chromosomal replication or degraded promptly to tritiated water and non-volatile tritium compounds, such as beta amino-isobutyric acid, and then excreted [8,9,14]. In these studies, the injection of tritiated thymidine one hour before killing flash-labeled the cells that were actively synthesizing desoxyribonucleic acid during the short, effective availability time (about twenty minutes for tritiated thymidine). Thus, in these studies, questions as to cell transformation cannot be answered since the one hour between injection and killing is less than the approximate minimum time needed for cells to proceed from desoxyribonucleic-acid synthesis through mitosis [3,12]. In other studies, serial killings after a single injection of tritiated thymidine have permitted observation of the transformation of osteoblasts into osteoclasts [18,20] and other cell transformations associated with bone growth, aging, and repair [19].

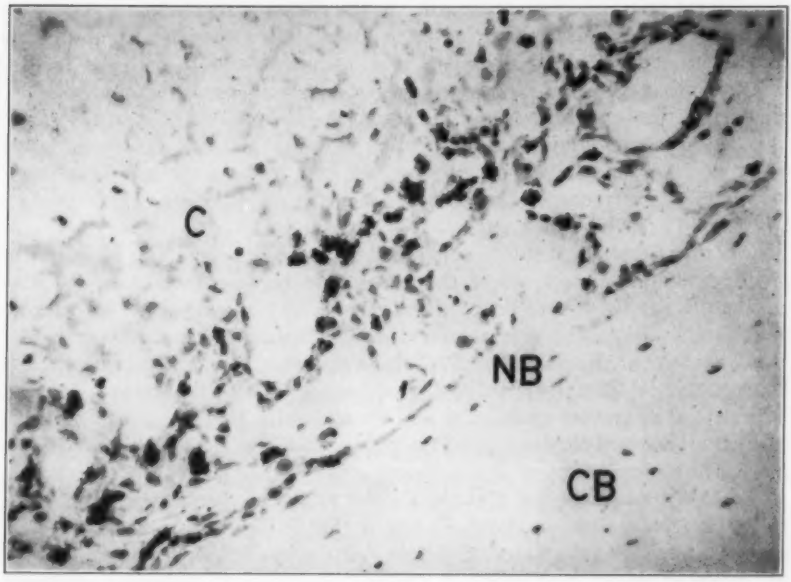

FIG. 7

The autoradiograph prepared three days after fracture reveals the presence of numerous labeled cells in the process of laying down new bone, *NB*, over cortical bone, *CB*, by conversion of the present cartilaginous callus, *C* (hematoxylin, × 235, oil immersion).

The labeling index (I_c) is defined as the ratio of the number of cells labeled to the total number of cells of the same cytological type observed:

$$I_c = \frac{C_e}{C_a} = \frac{{}^tDNA}{{}^tG}$$

Hence, if each cell of a particular cytological type retains the capacity to divide, the labeling index will approximate the ratio of the time for desoxyribonucleic-acid synthesis (^tDNA) to the average time between successive cell divisions (^tG) in a steady-state system of proliferating cells. However, in systems in which the rate of cell proliferation is changing from a relatively quiescent state, as in the periosteum of non-growing or slowly growing bone, to a changing state characterized by rapidly proliferating cells, interpretation would necessitate determination of the fine structure of the labeling-index curve with relation to time in order to follow the second derivative through its positive and negative phases as the labeling index returns to normal values.

In steady-state systems and in exponentially expanding tumors, ^tDNA has been shown to be of the order of five to twelve hours [3,10,11,12].

Fracture Repair

The earliest autoradiographically detectable cellular response to femoral fracture appeared as an increase in proliferation. This was observed sixteen hours after trauma. The proliferative response which extended throughout the entire length of the diaphysis was not limited to the periosteum or fracture site but also involved mesenchymal cells outside the periosteum. Maximum proliferative response (25.4 per cent) was seen in the periosteum thirty-two hours after fracture. These data are important since they show that the initial cellular reaction to skeletal trauma is generalized, yet not so widespread as to involve the epiphy-

ses, adjacent uninjured long bones, such as the tibia and fibula, and the uninjured control leg. These findings have led us to speculate that perhaps some substance normally present within the circulation is made available to periosteal cells by the traumatic rupture of blood vessels. No convincing evidence is available at present to indicate that this is anything more than a speculative hypothesis. However, in the section studied, an infiltration of white cells and fluid coming from ruptured vessels and surrounding tissues was seen in the muscle and connective-tissue elements surrounding the diaphysis along its whole length. Experiments are in progress in our laboratory to test this hypothesis.

Another aspect of the data seems important to consider. The initially widespread proliferative response of the periosteum became more localized about the fracture site thirty-two hours after fracture. This may indicate that for continued proliferation, the presence of a local stimulating factor is necessary. In areas where the proliferation potential of the periosteum diminishes with time, the elements derived from the circulation also diminish. About the fracture site, these elements are in greater abundance and consequently take longer to disappear. During the time that they are present a sufficient population of cells becomes available for fracture repair.

In 1918, Bier suggested that the fluid of a fracture hematoma contained an osteogenic factor. Urist and McLean found that autogenous transplants of fracture hematoma into the anterior chamber of the eye failed to form bone within four weeks. This result is evidence against Bier's theory. However, at present, there is no evidence against the possibility that the circulatory elements responsible for fracture healing act by stimulating the proliferation of periosteal cells, which are osteogenic. Were this true, intra-ocular transplants of fracture hematoma would fail to cause bone formation.

If the hypothesis is correct, it would be easy to see why new-bone formation can take place in relation to a bone transplant, even in the anterior chamber of the eye, away from other skeletal tissues. The circulatory elements which surround the viable transplant in the eye would stimulate proliferation of osteogenic cells. In the presence of adequate bone surface, such as is available in fractures, bone formation occurs. It is noted that in the samples used by Urist and McLean, all those which resulted in bone formation could have included viable osteogenic cells, whereas those which did not elicit bone formation would appear to have been free of viable osteogenic elements, such as pre-osteoblasts or osteoblasts.

From the results of numerous experiments reported in the literature on new-bone formation we believe that three basic requirements may be needed for bone formation to take place:

1. Free circulatory elements (resulting from trauma to vascular channels). A proliferation-stimulating factor, which resides in the plasma or lymph or is produced by white cells, may be made available by trauma;

2. Adequate surfaces on which bone formation may take place (the fracture surfaces themselves and the denuded adjacent bone ends produced by trauma to the bone proper);

3. Cells with osteogenic potency (for example, periosteal osteogenic cells, osteogenic cells covering cancellous bone, and perhaps reticular cells).

Evidence for the need of not only viable cells, but also cells with adequate osteogenic potency was shown by the experiments of Urist and McLean. These investigators showed that intra-ocular transplants of periosteum from three-week-old rats produced bone, whereas no bone was produced by transplants from one-year-old animals. It was recently demonstrated autoradiographically, using tritiated thymidine, that periosteal proliferation in these animals was very low at eight weeks of age [17,19]. Cytochrome-oxidase and succinic-dehydrogenase activity was also much reduced at this age [15,16].

Endosteum

No autoradiographic evidence was obtained to confirm a significant role of the subcortical endosteum in internal callus formation. Ham and Harris stated that the internal callus is formed from endosteum of the marrow cavity, in part, the endosteum of Haversian canals, and from undifferentiated mother cells of the marrow. The proliferative potential of the endosteum lining the cortex of the shaft is very low and was altered little during the entire period of fracture repair. On the other hand, osteogenic cells within the intertrabecular spaces and the osteoblasts lining the trabeculae were heavily labeled with tritium. It is our impression that, for the greatest part, these cells form the internal callus.

SUMMARY

An autoradiographic study of femoral-fracture repair using tritiated thymidine was made on forty-two female mice, five weeks of age.

Assessment of the periosteal labeling index was obtained from one hour to fourteen days after fracture.

Results showed that the initial proliferative response is seen in the periosteum and adjacent soft tissues sixteen hours after fracture. No increase in proliferation was observed at eight hours. The reaction was not limited to the fracture site but extended along the entire femoral diaphysis. The maximum increase of the labeled periosteal population (25.4 per cent) was observed at thirty-two hours after fracture.

After thirty-two hours, the size of the labeled population decreased with increasing time. The decrease was more apparent away from the fracture site, so that within five days of fracture the proliferative potential was similar to that of the non-fractured control femur. Fourteen days after fracture, the labeled population of periosteal cells at the fracture site was still above the value of the controls. The course of fracture repair was followed autoradiographically.

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Ischiofemoral Arthrodesis

An End-Result Study of Forty-four Cases*

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The purpose of this paper is to review the results of ischiofemoral arthrodesis by the Brittain technique in forty-four patients. These procedures were performed between 1947 and 1959 at four different hospitals by twelve surgeons, nine of whom were surgical residents doing their orthopaedic training.

CLINICAL MATERIAL

Arthrodesis was performed because of tuberculosis of the hip in twenty-two patients, aseptic necrosis of the femoral head in ten, and postinfectional arthritis in six. The remaining procedures were performed for conditions such as old Legg-Perthes disease, old epiphysiolisthesis, degenerative arthritis, ununited fracture of the femoral neck, and paralytic dislocation. In all instances, the contralateral hip was normal. The ages of the patients in this series ranged from four to sixty-eight years. The average age was 29.2 years. Only fifteen of the forty-four patients were in the first two decades of life; six were fifty years old or older. The minimum follow-up was eighteen months; the maximum, 144 months. Eleven patients were followed for eighteen to thirty-six months, fifteen were followed for thirty-six months to sixty months, and eighteen were followed for sixty months or more.

TREATMENT

Operative Technique

Essentially the same operative technique was employed in all the cases in this series, except that the size of the tibial graft varied and a homogenous graft was used in two cases. The patient is placed on a fracture table with both feet bandaged to the foot pieces and the pelvis is supported on the sacral rest so that the buttock is free. Two x-ray tubes are arranged for anteroposterior and lateral roentgenograms of the hip during the surgical procedure. After suitable surgical preparation of the whole limb, the lateral femoral cortex at the base of the trochanter is exposed subperiosteally through a lateral incision, splitting the vastus lateralis in the direction of its fibers. A guide wire, one-sixteenth of an inch, is then drilled through the femur, starting at a point just above the level of the lesser trochanter and aiming it at the ischium just below the inferior margin of the acetabulum. The position of this wire is checked by anteroposterior and lateral roentgenograms. When the position of the wire is satisfactory, drill holes are made through the femoral shaft parallel to and at the level of the guide wire, and an osteotomy of the femur at this level is performed. The opposing surfaces of the osteotomy are separated by traction through the foot piece, and Brittain or Starr osteotomes are inserted into the ischium. When these osteotomes have been proved to be in satisfactory position by anteroposterior and lateral roentgenograms, a tibial graft is inserted. This graft has been removed from the ipsilateral tibia by another operating team. The graft includes full thickness of the medial cortex, as well as the anterior crest and medial border. One end of the graft is

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TABLE I

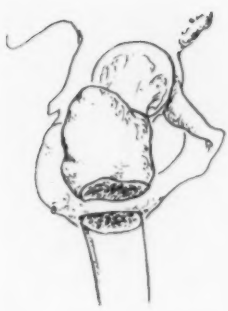
SUMMARY OF FORTY-FOUR BRITTAIN FUSIONS

Case	Age (*years*)	Sex	Race	Disease	Date of Operation	Clinically Solid	Complications	Present Condition	Functional Result
1	25	F	Negro	Tuberculosis	8–6–48	6–7–49	Concomitant tuberculosis of spine	Fused?	Tuberculosis arrested, both areas; slight limp
2	46	M	Caucasian	Aseptic necrosis	7–6–56	8–1–57	None	Fused; slight adduction	Walks well; slight limp
3	36	M	Negro	Tuberculosis	8–6–52	8–7–53	None	Fused	Slight limp
4	31	M	Caucasian	Aseptic necrosis	6–7–57	1–10–58	None	Fused	Works as lineman
5	14	F	Negro	Postinfectional arthritis	6–13–56	6–15–57	None	Fused	Almost no limp; full range of knee motion
6	14	M	Caucasian	Tuberculosis	4–12–56	2–12–57	None	Fused	Tuberculosis arrested; slight limp
7	60	M	Caucasian	Fracture, neck of femur	7–28–59	Not solid	Ununited ischium	Unfused, 4–6–60	Severe, painless limp; marked restriction of knee motion
8	24	F	Negro	Tuberculosis	3–7–56	6–7–58	None	Fused	Slight limp; knee motion 180 to 45 degrees
9	28	F	Negro	Postinfectional arthritis	4–25–55	1–18–58	None	Fused	Slight limp
10	45	M	Caucasian	Osteo-arthritis	12–7–57	3–8–58	None	Sequestrated graft, fused	Limp; knee motion 180 to 90 degrees
11	9	M	Caucasian	Tuberculosis	6–1–55		Graft sequestrum; ischiofemoral graft failed	Iliofemoral fused, 6–27–56	Slight limp; full knee motion
12	29	M	Caucasian	Traumatic dislocation	6–12–58	6–12–59	None	Fused	Slight limp; knee motion 180 to 60 degrees
13	38	M	Caucasian	Aseptic necrosis	10–14–58; 12–2–58		Temporary palsy, peroneal branch, sciatic nerve; graft ununited to ischium; infection	Unfused; 4–6–60; graft sequestrum	Painful limp; knee motion 180 to 160 degrees
14	30	M	Negro	Tuberculosis	7–3–55	10–15–58	None	Draining abscess before operation; fused	
15	7	F	Negro	Tuberculosis	4–16–53	2–1–54	Graft fractured; 3 mos. in plaster	Fused	Arrested tuberculosis; limp; full knee motion

16	50	M	Negro	Tuberculosis	5–15–58	9–15–58	None	Fused, 3 mos.	Knee motion 180 to 90 degrees
17	50	M	Negro	Aseptic necrosis	11–10–58	5–15–59	Two fusions required	Fused	Knee motion 180 to 80 degrees
18	12	F	Caucasian	Tuberculosis	5–10–52	1–10–53	Supracondylar fracture; flexion contracture, hip; subtrochanteric osteotomy	Fused	Full knee motion; limb equality
19	30	F	Caucasian	Pyogenic infection	8–6–48	8–11–49	Donor-site tibial fracture	Fused	Very slight limp; knee motion 180 to 80 degrees
20	35	F	Negro	Tuberculosis	3–17–49	1–7–52	None	Fused	Moderate limp
21	46	M	Negro	Aseptic necrosis	5–15–56; 7–12–56 (re-fusion)	2–14–58	None	Fused	Moderate limp
22	9	M	Negro	Pyogenic infection	9–15–48		Non-fusion to ischium	Unfused	Fibrous, painless fusion; slight limp
23	43	M	Caucasian	Aseptic necrosis	10–9–52		None	Unfused	Fibrous, painless fusion; abduction limited; adduction, 50 per cent; flexion, 50 per cent; ¾-inch shortening of limb; slight limp
24	24	M	Negro	Tuberculosis	10–29–53	4–30–54	None	Fused	Arrested tuberculosis; does heavy labor; very slight limp; knee motion 180 to 45 degrees
25	36	M	Negro	Tuberculosis	9–3–48	5–7–49	None	Fused	Slight limp; knee motion 180 to 90 degrees
26	52	M	Negro	Aseptic necrosis	6–26–57	1–15–58	None	Fused	Moderate limp; knee motion 180 to 120 degrees
27	40	M	Negro	Aseptic necrosis	6–16–58	12–10–58	None	Fused	Moderate limp; knee motion 180 to 100 degrees
28	35	F	Caucasian	Tuberculosis	12–8–55	6–15–56	Tuberculous abscess, hip and ipsilateral foot; hip abscess was draining before fusion	Fused	Arrested tuberculosis; moderate limp; knee motion 180 to 90 degrees
29	31	M	Negro	Tuberculosis	1–16–58	7–10–58	None	Fused	Moderate limp; knee motion 180 to 110 degrees

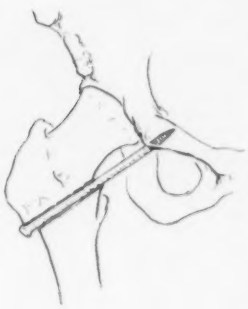
TABLE I—*Continued*

Case	Age (*years*)	Sex	Race	Disease	Date of Operation	Clinically Solid	Complications	Present Condition	Functional Result
30	12	F	Negro	Tuberculosis	1–2–58	2–2–59	Flexion-adduction contracture, hip	Unfused	Painful, fibrous fusion; in poor position
31	16	M	Caucasian	Tuberculosis	8–28–52	1–17–53	None	Fused	Very slight limp; knee motion 180 to 35 degrees
32	12	M	Caucasian	Legg-Perthes	6–3–52	8–11–58	Re-fused after initial failure	Fused	Very slight limp; knee motion 180 to 35 degrees
33	16	M	Negro	Infectious arthritis	1–19–55	9–7–56	Delayed fusion	Fused	Limb shortening, 3 inches; knee motion 180 to 45 degrees
34	15	M	Caucasian	Tuberculosis	7–10–52	1–15–53	None	Fused	Very slight limp; knee motion 180 to 45 degrees
35	4	M	Negro	Tuberculosis	1–19–53	8–21–53	Successful ischiofemoral fusion after initial failure of iliofemoral fusion	Fused	Limb equality; slight limp; knee motion 180 to 35 degrees
36	14	M	Negro	Charcot, paralytic dislocation	4–9–58	4–16–59	Ipsilateral supracondylar fracture	Fused	Slight limp; knee motion 180 to 45 degrees
37	16	M	Caucasian	Tuberculosis	8–19–49	2–11–50	None	Fused	Slight limp; knee motion 180 to 35 degrees
38	38	M	Negro	Tuberculosis	2–24–54	3–7–58	None	Fused	Arrested tuberculosis
39	68	M	Negro	Aseptic necrosis	2–24–53	Death; cancer of tonsil, 8–30–53		Not fused at time of death	
40	46	F	Caucasian	Postinfectional arthritis	9–7–55	6–10–57	None	Fused	Slight limp; knee motion 180 to 90 degrees
41	50	F	Negro	Osteo-arthritis	4–17–58	11–18–58	Loss of knee flexion	Fused	Severe limp; knee motion 180 to 160 degrees
42	52	M	Negro	Tuberculosis	6–26–57	7–28–58	None	Fused	
43	6	M	Negro	Tuberculosis	6–10–57	Graft removed, 4–1–58	Complete range of hip motion	Unfused	Tuberculosis arrested; complete function, hip and knee
44	16	M	Caucasian	Aseptic necrosis	6–28–59	2–24–60	Thrombophlebitis	Fused	Knee motion 180 to 90 degrees; ¾-inch shortening of limb



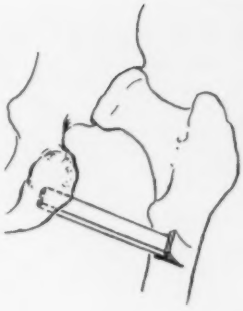
De Beule - Bosworth

FIG. 1-A



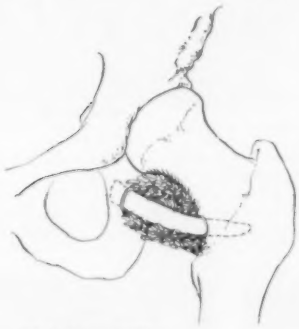
Brittain

FIG. 1-B



Trumble

FIG. 1-C



Kirkaldy-Willis anterior approach

FIG. 1-D

CHARNLEY

FIG. 1-E

Figs. 1-A through 1-D: Four strictly ischiofemoral hip fusions.
Fig. 1-E: Charnley compression-type fusion.

sharpened like a chisel, and this end is driven into the ischium between the chisels, which are removed once the graft has entered the slot in the ischium. Again, roentgenograms are made to check the position of the graft. If this is satisfactory, the wound is closed, and a spica cast is applied that extends from the nipple line to the toes on the affected side and to the knee on the normal side. The spica cast is applied with the hip in extension, since, as shown by Thompson, when a patient is on a fracture table, the sag of the body is such that the hip is in 15 degrees of flexion. The ideal position of the hip is considered to be 10 to 15 degrees of abduction, 20 degrees of flexion, and no rotation.

In ten cases not included in this series, double grafts were used. These grafts included the usual Brittain ischiofemoral graft and, in addition, a massive tibial graft driven through the greater trochanter along the superior aspect of the neck into the ilium just above the superior margin of the acetabulum. The patients treated in this fashion have not been followed long enough for end-result evaluation, but the results to date are encouraging.

Postoperative Management

All patients in this series were kept recumbent, immobilized in a spica cast for six months, except for two who were immobilized for a total of nine months. Most of the patients returned for their initial follow-up examination three months

FIG. 2-A

FIG. 2-B

Fig. 2-A: Roentgenogram of Case 33, a Negro boy, made in 1954, when the patient was sixteen years old. The hip was painful but the etiology was undetermined. The flattening of the femoral head suggests an old septic necrosis or postpyogenic destructive process.

Fig. 2-B: Twelve months after Brittain fusion. The fusion appeared to be solid, but there was gross motion clinically at the site of the subtrochanteric osteotomy. The graft appeared to be fused solidly into the ischium.

FIG. 2-C

FIG. 2-D

Fig. 2-C: Twenty-four months after fusion. There was some decreasing motion in the osteotomy site.

Fig. 2-D: Thirty-one months after fusion. Motion is somewhat less, and an increasingly strong bone bar is noted in the ischiofemoral region.

after operation. If the cast was foul smelling or broken, it was removed after first placing the patient on the fracture table, and a new cast was applied after roentgenograms of the hip were made. The new cast was worn for three more months. All patients were encouraged to turn over in bed, using an overhead frame. They were also instructed in bilateral quadriceps exercises. None was allowed to walk in the spica cast, and, to prevent motion of the knee, the casts were not bivalved.

Immobilization was discontinued after nine months, even if fusion had not occurred, since it was considered illogical to continue immobilization for a longer period (Fig. 7). After six months of immobilization, the spica cast was removed (1) if there was clinical evidence of fusion (femur and pelvis moving as one piece);

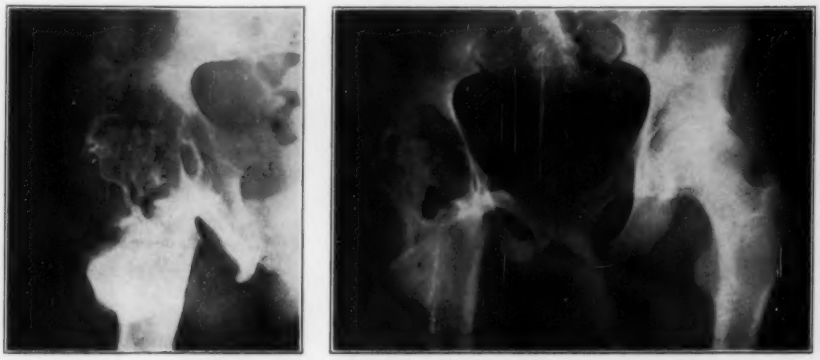


FIG. 2-E

Forty-eight months after fusion. There is approximately three inches of shortening, with solid clinical fusion. There is roentgenographic evidence of a large bone bar in the ischiofemoral region, together with bone trabeculae across the hip joint.

(2) if the adductor muscles were flaccid and atrophic; (3) if, as rarely occurred, bone trabeculae could be seen crossing the hip joint; (4) if the tibial graft had been incorporated and a strong continuous bar of bone had formed between the femur and the ischium (Fig. 2-D); and (5) if there was atrophy of the greater trochanter above the graft and if new trabeculae were visible, arranged along the lines of stress passing through the ischiofemoral graft (Fig. 2-E). If these indications of fusion were present, immobilization was discontinued, and the patient began to walk with crutches. After resumption of weight-bearing, fusion continued to progress (Figs. 2-A through 2-E).

RESULTS

Solid fusion developed in thirty-six of the forty-four hips. Two of these thirty-six hips required two Brittain arthrodeses before solid fusion was obtained (Cases 17 and 32, Table I).

In patients with successful fusion there was no limitation of motion of the foot or ankle. Similarly, there was no loss of knee motion in the patients twenty years of age or younger. In the patients over twenty years of age, more or less loss of knee flexion occurred. The greatest loss of knee motion occurred in a Negro female, fifty years old, who was immobilized for six months after hip fusion for degenerative arthritis. She regained only 20 degrees of knee flexion. None of the patients in this series who were over twenty years of age regained normal motion of the knee. The average amount of knee motion regained by the patients over twenty years of age was not determined.

All patients in this series with solid fusion walked with a slight limp, but were able to walk unlimited distances consistent with their ages. In general, the younger patients, because of more flexible lumbar spines, had the most graceful gaits and the least limp. Shortening of the limb seemed to be the principal cause of limp.

None of the patients under thirty years of age complained of low-back pain. Of the older patients, fourteen, or 50 per cent, had more or less backache.

As a general rule, it was observed that the hips that were clinically fused at six months went on to eventual solid bone fusion, as evidenced by roentgenograms. There was a considerable lag between the development of clinical union and the appearance of roentgenographic evidence of bone trabeculae across the hip joint and through the ischiofemoral graft.

TABLE II

FATE OF EIGHT NON-UNIONS

Case	Age (Years)	Sex	Race	Disease	Type of Graft	Graft in Ischial Slot
7	60	M	Caucasian	Sequel to trauma	Low angle	No
11	9	M	Caucasian	Tuberculosis	Low angle	No
13	38	M	Caucasian	Sequel to trauma and prosthesis	High angle	No
22	9	M	Negro	Pyogenic infection	High angle	No
23	43	M	Caucasian	Post-traumatic aseptic necrosis	Homogenous; flat	No
30	12	F	Negro	Tuberculosis	Low angle	No
39	68	M	Negro	Post-traumatic intertrochanteric fracture	Low angle	No
43	6	M	Negro	Tuberculosis	Low angle	No

COMPLICATIONS

There was one fatality due to cardiac arrest during the induction of anesthesia. This occurred before the development of cardiac massage and other resuscitative measures.

There was one temporary palsy of the peroneal branch of the sciatic nerve after a second ischiofemoral arthrodesis, using a posterolateral approach (Case 13). The sciatic nerve was identified during the procedure, but, apparently, it was retracted too vigorously. Complete return of motor power and sensation occurred in thirty-six months. It is perhaps worthy of note that there is no recorded instance in the literature of damage to the sciatic nerve when the lateral approach was used for the Brittain procedure with the pelvis supported on a sacral rest and the buttocks lying free.

Postoperative thrombophlebitis in the limb on which the surgery was performed developed in one patient, with enough swelling of the extremity to require change of the spica cast three months after operation (Case 44). In this patient solid fusion eventually developed.

One patient (Case 1, Table I) had a draining sinus on the lateral aspect of the hip from which acid-fast organisms were cultured before arthrodesis. This healed, and a successful Brittain fusion was carried out. Approximately six months after operation, drainage from the lateral side of the hip recurred. Roentgenograms at this time showed no further progression of the disease in the hip, but there was involvement of the lumbar spine. Treatment with streptomycin and a spine fusion resulted in apparent arrest ten years later.

In two patients, tuberculous abscesses were present before arthrodesis, but successful fusions were achieved without the development of tuberculous sinuses.

There were no postoperative infections at the donor site. One displaced oblique fracture at the lower end of the defect left by removal of the graft occurred nine months after operation in an older patient (Case 19, Table I).

Two supracondylar fractures of the femur on the side of the fusion occurred

TABLE II *(continued)*

FATE OF EIGHT NON-UNIONS

Operator	Period of Immobilization	Stability before Surgery	Final Disposition
Resident	9 mos.	Stable; prior hip prosthesis, followed by Urist cup, which was left *in situ* for Brittain procedure	Limited, but painless weight-bearing
Resident	6 mos.	Initial fibrous fusion; stable	Initial Brittain procedure, 1955; iliofemoral arthrodesis, 1956
Resident	6 mos.	Stable; reinsertion of graft (Brittain)	Painless, limited hip motion; weight-bearing
Resident	6 mos.	Stable; fibrous fusion	Painless, limited hip motion; weight-bearing
Staff	6 mos.; 2 casts	Stable with equal limited motion	Non-union; patient walks without pain; hip motion approximately 50 per cent limited in all directions
Staff	6 mos.; 2 casts	Stable; biopsy 2 wks. prior to fusion	Painful adduction flexion contracture; no further surgery
Resident	6 mos.; 2 casts	Stable	Initial failure of Brittain procedure; later bone graft and plate; patient died
Resident	6 mos.; 2 casts	Stable; biopsy 2 wks. prior to fusion	Full range of motion; painless absorption of graft; arrested tuberculosis

eighteen months (Case 18) and twenty-four months (Case 36) after arthrodesis.

There were no injuries to the external iliac and obturator vessels or to the bladder and urethra. Cadaver dissections (Figs. 4-A and 4-B) indicated that the iliopsoas muscle forms a protective cushion one to one and one-half inches in thickness on the medial side of the ischium. As a result, it is believed that the Brittain or Starr osteotomes or the graft can penetrate the medial cortex of the ischium completely without causing damage to these vital structures.

The ischiofemoral graft fractured in one patient (Case 15) three months after operation while the patient was still immobilized. The fracture united, however, with further immobilization, and solid fusion resulted.

There was one delayed union (Case 33) of the femoral osteotomy (Figs. 2-A through 2-E). This finally united after six months of immobilization and forty-two months of ambulation.

Delayed fusion occurred in one other case, that of a Negro man, fifty years old, when the spica cast was removed inadvertently three months after operation. A second ischiofemoral arthrodesis was attempted six months later, but it proved impossible to insert the new graft into the ischium. The hip was immobilized in a spica cast six months after this procedure, and solid fusion resulted (Figs. 6-A through 6-D).

ANALYSIS OF FAILURES

There were eight failures in this series. Among these there was one homogenous and seven autogenous tibial grafts. Four of these grafts included the anterior crest and medial border, and four included just the cortex of the anteromedial surface. The angle of insertion of the graft was 0 degree, or horizontal, in one; 0 to 30 degrees in four; and 30 to 45 degrees in three. In all the failures there was doubt at the time of operation whether the medial end of the graft was really solidly implanted in the slot in the ischium. All the failures occurred at the medial end of the graft. The graft fused to the femur in all instances, but the lateral por-

FIG. 3-A

FIG. 3-B

Figs. 3-A and 3-B: This patient, H.E. (not included in the series reported), had proved tuberculosis of the left hip and had received streptomycin and isoniazid for about thirty days.

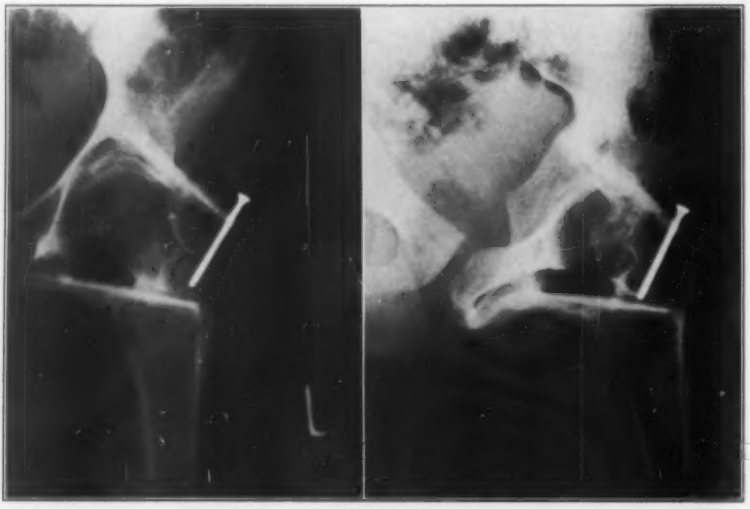


FIG. 3-C

Nine months after double-compression tibial-graft arthrodesis of the left hip.

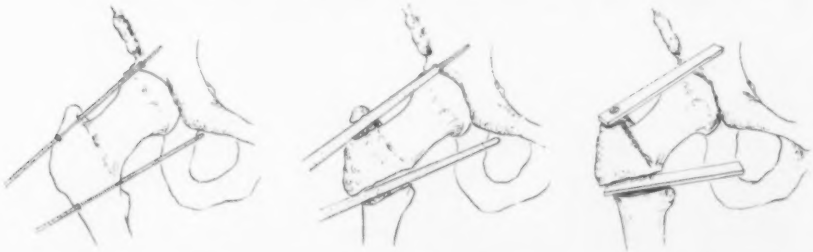


FIG. 3-D

Diagram of procedure used in Patient H.E. showing: insertion of double guide wires; double osteotomes; and double bone grafts.

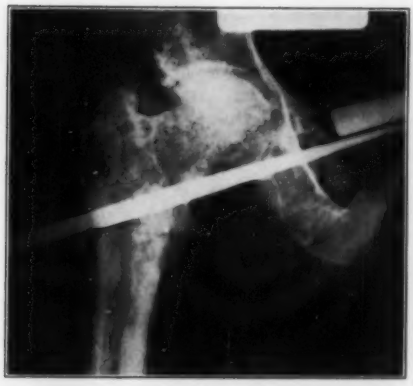


FIG. 4-A

FIG. 4-B

Fig. 4-A: The osteotome is inserted in a cadaver in the subacetabular region, extending into the pelvis itself. The osteotome extended approximately one inch beyond the muscle in this area, as visualized with the butt of another osteotome just visible. This shows a large margin of safety in insertion of the osteotome itself.

Fig. 4-B: A tibial graft is inserted in this same slot and demonstrates that even though the medial portion of the graft protrudes into the ischium itself, as shown by roentgenogram, it is not visible on the pelvic side.

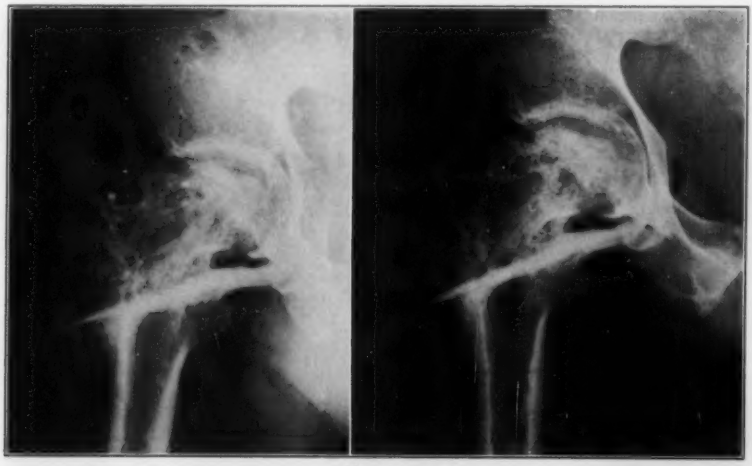


FIG. 5

Case 4, eighteen months after fusion for post-traumatic aseptic necrosis of the head of the right femur. The patient works daily as a lineman.

tion of the graft was removed as a sequestrum after fusion had taken place in two patients (Cases 11 and 13).

All of the eight hips in which failure occurred were stable before operation, with varying degrees of motion present.

The indications for arthrodesis in this group were tuberculosis in three cases, old septic arthritis in one, and post-traumatic changes in four. In one patient, a Negro boy, six years old, with tuberculosis proved by biopsy, the medial end of the graft absorbed. The graft was subsequently removed (Case 43). Happily, as the result of immobilization and treatment with anti-tuberculosis drugs and a one and one-half hip spica for six months, the hip disease was arrested. The boy has remained well, with normal hip motion.

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 17, two years after McMurray osteotomy of the femur for non-union of a fracture of the neck of the femur.
Fig. 6-B: Five months after initial fusion; three months of cast only.

FIG. 6-C

FIG. 6-D

Fig. 6-C: A second Brittain graft could not be passed medially into the ischial slot.
Fig. 6-D: Nine months after the second operation; there was healing clinically and as seen by roentgenogram.

Of the seven other patients with failure of fusion, three have fibrous union but are walking without pain; two have had iliofemoral fusion and now have solid iliofemoral, intra-articular, and ischiofemoral fusion; one has occasional pain but does not wish further treatment; and one (Case 39) died six months after arthrodesis as the result of cancer of the tonsil.

DISCUSSION

Many ingenious methods for intra-articular, para-articular, and extra-articular fusion of the hip have been devised since Albee first described his pro-

cedure in 1908. The reported incidence of pseudarthrosis after these procedures has ranged from 20 to 50 per cent. Cholmeley found that the incidence of pseudarthrosis after iliofemoral fusion was reduced from 36 to 12 per cent by the addition of a subtrochanteric osteotomy.

Ischiofemoral arthrodesis was reported in 1909 by De Beule, who transplanted the proximal end of the femoral shaft into the ischium. A similar procedure was employed by Bosworth in 1942. Trumble, in 1932, reported his technique for ischiofemoral fusion in which a posterior approach was employed, and a tibial graft was implanted in slots cut in the ischium and subtrochanteric

FIG. 7

Case 13. The roentgenogram suggests solid fusion, but there was obvious motion on clinical examination.

region of the femur without osteotomy of the femur. Brittain described his technique in 1941. Modifications of the Brittain and Trumble fusions were described by Foley and Van Gorder. Kirkaldy-Willis [33,34] described still another technique for ischiofemoral arthrodesis, using cancellous bone from the adjacent ilium and placing this through an anterior approach. A technique for combined ischiofemoral and pubofemoral arthrodesis through the medial approach was described by Coolican.

Brittain is largely responsible for the development and popularization of ischiofemoral arthrodesis. Many others [11,18,19,20,24,36,53] have also made significant contributions to the development of this procedure. There are many reports of successful results with this technique in the European literature [3,4,5,7,21,25,26,27,28,40,44,45,47,48,49,50,51,57,59,60,61], but Mayer reported unfavorably on this method in 1948.

The advantages claimed for ischiofemoral arthrodesis as described by Brittain are that it is extra-articular and hence does not either disseminate the local disease or disrupt a healing tuberculous lesion; in old pseudarthrosis with a smoldering tuberculous lesion, it is virtually the only method to obtain fusion; it allows the femoral head and neck to adduct so that the joint cavity is collapsed;

the technique lends itself well to fusion of unreduced congenital dislocation of the hip and of subluxation of the hip, and to fusion of degenerative and post-traumatic osteo-arthritis of the hip where dense sclerotic bone about the hip joint interferes with fusion.

The biomechanics of the Brittain fusion are favorable to fusion [9]. The graft is placed in an area where the conditions for bone healing are favorable, and the graft is under compression rather than tension.

A common impression is that tuberculosis of the hip is the only indication for an ischiofemoral arthrodesis of the Brittain type. The results in the present series and the experience of others [11,15,18,23,36] demonstrate that this procedure is applicable to many disorders of the hip for which fusion is necessary. The specific indications for this procedure are believed to be tuberculosis, aseptic necrosis of the femoral head, old septic arthritis, osteo-arthritis, paralytic dislocation, nonunion of fractures of the femoral neck or intertrochanteric regions, and unsuccessful previous surgical procedures (arthroplasty or arthrodesis).

The contra-indications to this procedure are considered to be bilateral hip disease, inadequate bone in the ischiofemoral region owing to extension of disease into this region, and advanced age. The oldest patient in this series was sixty-eight years of age (Case 39). He died six months after surgery, with cancer of the tonsil. The hip was still not fused at the time of death. In general, hip fusion is not indicated in the aged because they tolerate prolonged immobilization poorly and, as a rule, live sedentary lives in which a fused hip makes sitting difficult.

The condition of the lumbar spine was not observed to influence the functional results in this series, but a full range of painless motion in the lumbar spine was necessary for a graceful gait and sitting posture.

Subtrochanteric osteotomy appears to increase the incidence of fusion after arthrodesis significantly. Indeed, subtrochanteric osteotomy alone may cause hip fusion [7]. In view of the success of subtrochanteric osteotomy in the relief of pain due to osteo-arthritis, it is possible that this is responsible for the relief of pain that is sometimes observed when ischiofemoral arthrodesis by this technique fails [16]. Relative fixation of the femoral head, such as by previous unsuccessful iliofemoral fusion, favors successful ischiofemoral fusion. By the same token, iliofemoral fusion is more likely to succeed in the presence of a previously unsuccessful ischiofemoral arthrodesis.

The review of this series has emphasized certain technical points of importance. The broad graft must be inserted firmly into the ischial slot. There must not be the slighest doubt that the graft is solidly fixed in the ischium at the conclusion of the operation. The Brittain chisel and Starr osteotomes are of great help, but they could be improved. The graft should probably be inserted at an angle of 30 to 45 degrees above the horizontal. The point of insertion for the guide wire, osteotomes, and graft should be at the level of the junction of the neck and femoral shaft just above the lesser trochanter. The positions of the guide wire, the osteotomes, and the graft must be checked by both anteroposterior and lateral roentgenograms. To accomplish this, the patient should be placed on a fracture table on the sacral rest with no support beneath the buttocks and x-ray units should be in place to enable both anteroposterior and lateral roentgenograms to be made.

From the results in this series it would appear that immobilization in a one and one-half spica cast for six months is sufficient to obtain fusion. Further development of the fusion may be anticipated after immobilization is discontinued. Because of the limitation of knee motion observed in the older patients in this series, it would seem desirable to bivalve the cast below the knee about six weeks

after operation to permit periodic exercise of the knee in an effort to preserve knee motion.

When immobilization in plaster is discontinued, crutches should be used for three months, followed by a cane for three months. In view of the nearly 2 per cent incidence of tibial fractures through the donor site in this series, prolonged protection is indicated.

An unsuccessful ischiofemoral arthrodesis may result in a painless gait. If refusion is indicated after an unsuccessful ischiofemoral fusion, the double, massive-compression tibial graft used in a few cases to date appears to have much to recommend it. All patients with hip fusions should be followed for at least three years if the true end results are to be determined.

SUMMARY

In this series of forty-four patients with Brittain ischiofemoral arthrodesis of the hip performed for tuberculosis, aseptic necrosis of the femoral head, postinfectional arthritis, degenerative arthritis, and miscellaneous conditions, solid fusion was obtained in thirty-five (80 per cent) of the forty-four patients. In all the failures, the tibial graft had not been inserted firmly into the ischium; this appeared to be the chief cause of failure. All patients were immobilized for from six to nine months in a plaster spica cast. No serious complications were encountered. It was concluded that ischiofemoral arthrodesis is a satisfactory technique to achieve hip fusion in diseases of the hip other than tuberculosis.

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Complete Dislocation and Subluxation of the Acromioclavicular Joint

End Result in Seventy-three Cases *

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Despite literature replete on the subject of injuries of the acromioclavicular joint, there is still no agreement concerning management of these injuries. With this in mind, we have studied the end results of treatment of dislocations and subluxations of this joint to try to determine the best management. The classic articles of Cadenat and Urist [16] have covered the etiology and, in addition, have reviewed the literature most completely.

COMPLETE DISLOCATION OF THE ACROMIOCLAVICULAR JOINT

According to Urist [16,17] there are thirty-five conservative methods and twenty-eight operative methods of treating dislocation of the acromioclavicular joint. Basically, surgical treatment can be divided into: (1) fixation of the acromioclavicular joint by wires, screws, pins, or fascial suture until the injured ligaments heal [2,12,13]; (2) arthroplasty with excision of the outer end of the clavicle [6,10,11]; (3) fixation of the coracoid to the clavicle by a screw [2,18]; and (4) repair of the coracoclavicular ligaments with fascia [2,7,14].

Conservative treatment has been of three types: (1) adhesive dressings [19], (2) various harnesses and braces [1,5], or (3) hanging-type casts (suspension casts) [15,20]. The various types of apparatus were well annotated by Urist [16]. In his opinion and, more recently, in the opinion of Stubbins and McGaw, some type of cast, either a spica or circular body cast, that exerts positive relocation pressure on the clavicle is the best method of maintaining reduction.

During the thirteen-year period from 1945 through 1957, forty-three patients seen at the Mayo Clinic by members of the Section of Orthopedic Surgery had complete dislocation of the acromioclavicular joint. Forty of them had symptoms severe enough to warrant treatment, and three had old asymptomatic dislocations that required no treatment. Of the forty patients requiring treatment for complete dislocation, twenty-two had recent injuries (that is, they were seen eight days or less from the time of the original injury), and eighteen had old or neglected dislocations. Five of the patients were treated by closed methods, and thirty-five were treated by various surgical procedures.

During the same period, thirty-seven patients were treated for incomplete dislocation of the acromioclavicular joint; conservative measures were employed for all.

At the time of writing, we had obtained follow-up data on thirty-nine of the forty patients with symptomatic, complete dislocations and on thirty-five of the patients with subluxations of the acromioclavicular joint. We had examined thirty-three of the patients treated for complete dislocation and obtained letters

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TABLE I

EXCISION OF THE OUTER END OF THE CLAVICLE WITH OR WITHOUT OTHER PROCEDURES

Case	Age (*Years*)	Sex	Duration of Dislocation	Follow-up* (*Years*)	Functional Result	Late Roentgenographic Findings	Occupation Before Injury	Occupation After Injury
Only excision of the outer end of the clavicle:								
1	76	M	1 day	1½	Excellent	Ossification in the coracoclavicular ligament; some upward displacement of the clavicle	Farmer	Farmer
2	56	M	11 mos.	10	Excellent	Ossification in the coracoclavicular ligament; some upward displacement of the clavicle	Architect	Architect
3	49	M	6 mos.	10	Excellent	No ossification; some upward displacement of the clavicle	Butcher	Butcher
4	48	M	4 mos.	12	Excellent	No ossification; some upward displacement of the clavicle	Welder	Welder
5	47	M	5 mos.	6 wks.	Excellent		Butcher	
6	43	M	7 mos.	8	Excellent	Ossification in the coracoclavicular ligament; some upward displacement of the clavicle	Laborer	Laborer
7	40	M	12 mos.	9 (letter)	Excellent		Smelterman in copper factory	Smelterman and small farmer
8	20	M	1 day	5	Excellent	Slight upward displacement of the clavicle	Student	Engineer
Excision of the outer end of the clavicle, insertion of lag screw, and fascial repair:								
9	37	M	1 mo.	2 (letter)	Excellent	Dislocation recurred after the lag screw was removed‡	Chemist	Chemist
10	63	M	10 mos.	6	Excellent	Ossification in the coracoclavicular ligament; dislocation‡	Farmer	Farmer
11	57	F	15 mos.	11	Excellent	Slight ossification in the coracoclavicular ligament; dislocation‡	Farm housewife	Farm housewife
12	42	M	1 wk.	10	Excellent	Dislocation recurred after the lag screw was removed‡	Tavern owner	Tavern owner
Excision of the outer end of the clavicle and insertion of lag screw:								
13	21	M	1 wk.	10 (letter)	Excellent	Reduction maintained at the time of removal of the lag screw	Student	Office worker
14	44	M	4 mos.	12	Fair†	Ossification in the coracoclavicular ligament; dislocation recurred after the lag screw was removed‡	Farmer	Farmer
Excision of the outer end of clavicle and fascial repair:								
15	47	M	3 yrs.	12 (letter)	Excellent		Short-order cook	Short-order cook

* Re-examination except when the word "letter" appears.

† No adequate explanation can be offered for the fair result; the ossification in the coracoclavicular ligament was no more than it was in others in this group.

‡ Dislocation was gradual, averaging one month after removal of the screw.

from six. All six patients followed by letter had been examined at the Clinic during the postoperative period, and the letters were used to confirm the clinical impression made at that examination. All patients were questioned about the amount of residual pain in the shoulder. A carefully measured range of motion was obtained, and the strength in both shoulders was evaluated. Roentgenograms of both shoulders were made while the patient was standing upright and holding sandbags in each hand. Although we noted the appearance of each patient, including the operative scar, we do not consider this an important point in assessing end results, because, even in untreated complete dislocations, the appearance of the shoulder, in our opinion, is not unsightly. This was especially true of our patients, since all but three were men.* Nonetheless, since the final appearance of the shoulder may sometimes be a factor in determining treatment, we attempted to evaluate this point.

For the result to be graded as *excellent*, absence of pain, objective and subjective absence of weakness, and an essentially normal range of shoulder motion were necessary. If pain, weakness, or limitation of motion of even a mild degree was present, we assigned a rating of *fair*. If pain, weakness, or limitation of motion of a moderate degree, either singly or in combination, existed, we assigned a rating of *poor*. In addition, we classed as *poor* the result in one patient who had periarthritis of the shoulder for one year after operation. This was caused by a low-grade wound infection. Eight years later the patient reported a painless, fully movable, and strong shoulder. We have been severe in our evaluations, but since our objective was to find the best and the simplest treatment for these injuries, strict evaluation seemed the only correct approach.

This system of rating is based entirely on functional results. Also included is a roentgenographic evaluation of the anatomical results, which are certainly important to the surgeon when evaluating the result of any operation for relocation of a joint.

Excision of the Distal End of the Clavicle for Complete Dislocations

Surgical excision of the distal portion of the clavicle and nothing more was performed in eight cases (Cases 1 through 8). Excision of the end of the clavicle in combination with other methods was performed in seven more (Cases 9 through 15, Table I). Basically, the procedure used for the excision of the outer end of the clavicle was that described by Gurd and by Mumford.

In most of these cases, approximately an inch of the clavicle was excised, and the trapezius and deltoid muscles were reattached accurately to the acromion and clavicle. In six of the seven cases in which concurrent procedures were performed, a lag screw was used to transfix the clavicle and hold it approximated to the coracoid. In four of these six, the coracoclavicular ligaments were also repaired with fascia lata from the patient's thigh, and in the other two a lag screw alone was used. In the seventh case (Case 15) the additional procedure consisted in a fascial repair of the coracoclavicular ligaments.

Functional Results

The results of excision of the distal end of the clavicle with or without other procedures were uniformly good except in Case 14 (Table I). In this one exception, the patient had mild limitation of motion and mild pain at the time of follow-up twelve years after operation. His occupation was sedentary, and he was well pleased with the result; still, we consider that he had only a fair functional result. Except for this single case, the excision of the outer end of the clavicle proved to be an excellent method.

* One of the three patients with asymptomatic dislocation was a woman.

FIG. 1-A

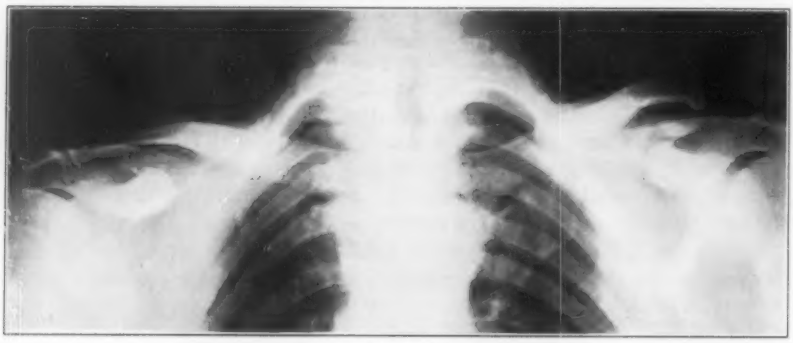

FIG. 1-B

Figs. 1-A and 1-B: Case 1. Complete acromioclavicular dislocation in a man, seventy-six years old.

Fig. 1-A: Left acromioclavicular joint after the initial injury.

Fig. 1-B: Thirteen months after excision of the outer end of the clavicle. Some ossification of the coracoclavicular ligaments and upward displacement of the clavicle are evident.

Late Roentgenographic Evaluation of Anatomical Results

Ossification in the region of the coracoclavicular ligaments after simple excision of the distal portion of the clavicle was noted in three of six patients whose roentgenograms were available for review. In all six there was persistence of the upward displacement of the clavicle, like that shown in Figures 1-A and 1-B.

The roentgenograms of patients treated by excision of the outer end of the clavicle combined with additional procedures were revealing. In five of the seven patients so treated, late follow-up roentgenograms were available (Cases 9 through 12 and Case 14) and disclosed evidence of upward dislocation. The degree of displacement is illustrated in Figures 2-A and 2-B. In another case (Case 13) the only roentgenograms available were made at the time of removal of the internal fixation; these showed maintenance of reduction at that time.

Appearance of the Shoulder

Patients treated by simple excision of the outer end of the clavicle had scars, which, in the examiner's opinion, were not unsightly. Also, the moderate upward

FIG. 2-A

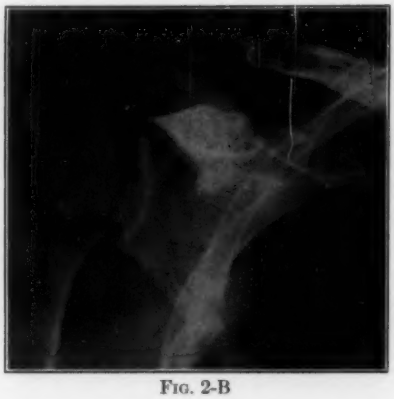

FIG. 2-B

Figs. 2-A and 2-B: Case 10. A ten-month-old complete acromioclavicular dislocation in a man, sixty-three years old.

Fig. 2-A: A fascial repair of the coracoclavicular ligaments has been performed in addition to resection of the distal end of the clavicle and insertion of the lag screw.

Fig. 2-B: The lag screw was removed two months after operation. The preoperative dislocation recurred gradually and is quite apparent in this roentgenogram made one month after removal of the lag screw.

displacement of the clavicle was not noticeable. To insert a lag screw and fascia, or either one separately, a more extensive exposure was required than for simple excision of the outer end of the clavicle. Although none of the patients who had additional procedures was unhappy about the appearance of his shoulder, the scars were more noticeable than those resulting from simple excision.

Fixation of the Acromioclavicular Joint with Wires, Screws, Pins, or Fascia Lata for Complete Dislocation

A variety of fixation devices was used in these fourteen cases. The largest group (six cases) was treated by fixation with Kirschner wires. A small screw was used in one case, and a Knowles pin was used in another. In six cases a fascial suture was used to fix the joint. The fascia was removed from the thigh with a Masson fascial stripper.

In all cases the acromioclavicular joint was inspected. If the articular disc was damaged, it was excised. After reduction and fixation of the acromioclavicular joint, the acromioclavicular ligament was repaired with absorbable sutures, if possible.

Functional Results

The results are given in Table II. Seven patients had excellent results, three had fair results, three had distinctly poor results, and one was lost to follow-up. The results in this group were not so good as in the other groups studied.

Late Roentgenographic Evaluation of Anatomical Results

All eight patients treated with wires, pins, or screws (Table II) had roentgenographic follow-up. In all except one (Case 20), reduction of the acromioclavicular joint was maintained. Four of the eight showed degenerative changes in the acromioclavicular joint in the late roentgenograms (Fig. 3-C). These changes may explain the results seen in Cases 16, 21, and 23, and, to some extent, Case 20.

Four of the six patients treated by a fascial suture through the acromioclavicular joint had long-term follow-up roentgenograms. Reduction of the joint

TABLE II

FIXATION OF ACROMIOCLAVICULAR JOINT BY WIRES, SCREWS, PINS, OR FASCIA

Case	Age (*Years*)	Sex	Duration of Dislocation (*Days*)	Fixation	Follow-up* (*Years*)	Functional Result	Late Roentgenographic Findings (Acromioclavicular Joint unless Otherwise Stated)	Occupation Before Injury	Occupation After Injury	Remarks
16	49	F	3	Kirschner wires	11/12	Poor	Ossification and degenerative changes in joint	Housewife	Housewife	Late roentgenographic findings in acromioclavicular joint may explain poor result based on pain in joint, limitation of shoulder motion, and weakness
17	44	M	20	Kirschner wires	8/12	Fair	Well reduced; some loosening and bending of wires during postoperative period	Dispatcher	Unemployed	Patient psychotic before injury and operation and did not follow instructions after operation; excessive motion after operation caused bending of wires; this may account for pain (not severe) in joint
18	43	M	2	Kirschner wires	6	Excellent	Well reduced; no degenerative changes	Farmer	Farmer	
19	43	M	1	Knowles pins	6	Excellent	Well reduced; no degenerative changes	Farmer	Inmate, hospital for mental patients	
20	33	M	4	Kirschner wires	8	Poor	Degenerative changes	Farmer	Farmer	Wires backed out at 2 wks. and had to be removed because of dangers of infection (Table III)
21	37	M	3	Kirschner wires	6	Fair	Well reduced; degenerative changes	Housewife	Housewife	Fair result because of mild pain, probably due to degenerative changes in the joint; motion normal
22	21	M	8	Kirschner wires	5	Excellent	Well reduced; some ossification of coracoclavicular ligament	Clerk in warehouse	Clerk in warehouse	
23	45	M	1	Small screw	4	Fair	Well reduced; degenerative changes	Priest	Priest	Mild pain due to marked degenerative changes in joint (Fig. 3-C)
24	28	M	2 mos.	Fascial suture	3½	Excellent	Well reduced; no degenerative changes	Farm manager	Farm manager	
25	28	M	5 mos.	Fascial suture	8 (letter)	Poor		Farmer	Farmer	Marked pericapsulitis after operation that loosened up after 1 yr.; poor result based on prolonged convalescence
26	19	M	8	Fascial suture	9½	Excellent	Well reduced	Farmer	Farmer	
27	10	M	1	Fascial suture	3	Excellent	Well reduced	Student	Student	
28	48	M	2 wks.	Fascial suture	8	Excellent	Slight subluxation of joint	Department store manager	Department store manager	
29	39	M	4 mos.	Fascial suture	No follow-up					

*Re-examination except in Cases 25 (letter) and 29.

FIG. 3-A

FIG. 3-B

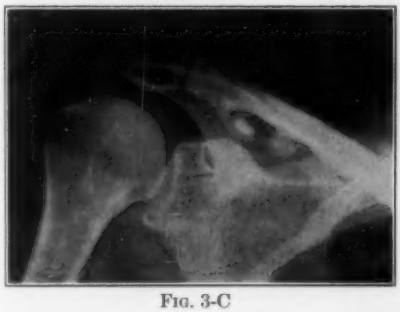

FIG. 3-C

Figs. 3-A through 3-C: Case 23. Dislocation of acromioclavicular joint.

Fig. 3-A: The dislocation is one day old.

Fig. 3-B: Fixation with a screw was performed. The screw was removed six weeks later.

Fig. 3-C: Marked degeneration is apparent in the acromioclavicular joint four years after operation. The patient had mild pain localized to the acromioclavicular joint. Shoulder motion was essentially normal.

was maintained in three, and slight residual subluxation was noted in one. No degenerative changes were noted in the acromioclavicular joint of those patients who had late roentgenograms.

Appearance of the Shoulder

The scar resulting from insertion of the Kirschner wires, pins, screws, or fascial sutures was similar to that resulting from excision of the outer end of the clavicle. In the examiner's opinion, these scars were not unsightly. In Case 28 a slight deformity had resulted from a partial recurrence with subluxation of the acromioclavicular joint; there were no other deformities.

Fixation of the Clavicle to the Coracoid with a Lag Screw for Complete Dislocation

Seven patients were treated by this surgical method alone (Table III). The procedure demands a certain degree of experience in surgery about the shoulder. The proper placement of the screw can be tedious. We believe that after a period of eight to twelve weeks the screw should be removed because of possible interference with shoulder motion, as described by Inman and associates. Although this is denied by Kennedy and Cameron, the bone absorption about the screw in the clavicle, noted at the time of removal, indicates that there was some stress on the clavicle, caused by this type of fixation.

Functional Result

Four patients had excellent results from this method of fixation, and three had fair results. Two patients (Cases 20 and 34) complained of mild pain in the region of the acromioclavicular joint, and one patient (Case 35) had mild restriction of shoulder motion, possibly owing to the excessive ossification in the region of the coracoclavicular ligament.

TABLE III

DATA ON CASES IN WHICH A CORACOCLAVICULAR LAG SCREW WAS INSERTED

Case	Age (*Years*)	Sex	Duration of Dislocation	Follow-up* (*Years*)	Functional Result	Late Roentgenographic Findings (Acromioclavicular Joint unless Otherwise Stated)	Occupation Before Injury	Occupation After Injury
20†	33	M	2 mos.	5	Fair	Reduced; degenerative changes	Farmer	Farmer
30	17	M	1 day	9	Excellent	Dislocation; moderate ossification in the coracoclavicular ligament	Student	Lawyer
31	27	M	7 days	4	Excellent	Reduced; slight degenerative changes	Farmer	Farmer
32	52	M	6 days	6½ (letter)	Excellent	Minimum subluxation	Farmer	Farmer
33	65	M	6 days	9	Excellent	Minimum subluxation	Telegraph operator	Retired
34**	19	M	4 mos.	10	Fair	Reduced; degenerative changes; moderate ossification in the coracoclavicular ligament	Grocery clerk	Grocery clerk
35††	56	M	3 mos.	10	Fair	Dislocation; marked ossification in the coracoclavicular ligament	Farmer	Farmer

* Re-examination except in Case 32 (letter.)

† Treated unsuccessfully by Kirschner wires; fascial repair of coracoclavicular ligament and insertion of coracoclavicular screw; mild pain, possibly due to degenerative changes in joint.

** Mild pain in joint, possibly due to degenerative changes.

†† Motion limited, possibly due to marked ossification in region of coracoclavicular ligament.

Late Roentgenographic Evaluation of the Anatomical Result

In all seven patients in this group we had long-term follow-up roentgenograms. In three (Cases 20, 31, and 34) degenerative changes involved the acromioclavicular joint. In one (Case 20) these changes may well have been secondary to the effect of the Kirschner wires that were used to transfix and immobilize the joint in the first operation. In two cases (Cases 30 and 35) we noted recurrence of dislocation of the acromioclavicular joint, and in two other cases (Cases 32 and 33), there was subsequent occurrence of minimum subluxation. Calcification in the region of the coracoclavicular ligament was present in three cases (Cases 30, 34, and 35). Figures 4-A through 4-C illustrate recurrence of dislocation after removal of the lag screw (Case 35) as well as excessive ossification in the region of the coracoclavicular ligaments. How soon the dislocation occurred after removal of the lag screw is difficult to say, but the displacement probably developed gradually. In every instance in which a coracoclavicular screw was used, bone absorption about the site of the screw in the clavicle was noted at the time of removal.

Appearance of the Shoulder

The surgical scars in this group were more apparent than those in the patients treated by simple excision of the distal end of the clavicle or by direct fixation of the acromioclavicular joint. The coracoid process was exposed during fixation of the clavicle with a lag screw; therefore, the resultant scar was more noticeable than the scars left after the other operations. In Cases 30 and 35, prominences due to recurrence of dislocation were visible. In two other cases (Cases 32 and 33) with recurrence of minimum subluxation, no prominences were noticeable.

FIG. 4-A

FIG. 4-B

FIG. 4-C

Figs. 4-A through 4-C: Case 35. Dislocation of right acromioclavicular joint in a man, fifty-six years old.

Fig. 4-A: Three-month-old unreduced dislocation.

Fig. 4-B: One week after insertion of a lag screw alone as fixation. The lag screw was removed three months after operation.

Fig. 4-C: Recurrence of dislocation and marked ossification in the region of the coracoclavicular ligament. Dislocation recurred gradually after removal of the lag screw.

Closed Reduction with Cast or Bandage for Complete Dislocations

The last method of treatment evaluated was closed reduction with external fixation. In four patients a suspension-type cast was used. In one case (Case 38) closed reduction was accomplished by manipulation of the distal end of the clavicle. Reduction was accompanied by an audible click over the joint. The reduction was then stable and was maintained with a Velpeau bandage. All these dislocations were acute, and four of the five patients were young.

Functional Results

The functional results were excellent in all five patients.

Late Roentgenographic Evaluation of the Anatomical Result

The late roentgenograms in this group of five patients revealed maintenance of reduction in four. In one there was evidence of slight recurrent subluxation on the upright roentgenograms made while the patient was holding weights in his hands.

Appearance of the Shoulder

In one patient (Case 36) a slight prominence was apparent over the distal end of the clavicle; otherwise the appearance of the shoulders of these patients was entirely normal.

SUBLUXATIONS

In this group the average period of follow-up was three and one-half years; it ranged from one month to twelve years. Various types of treatment, ranging from no more than physical therapy to suspension casts, had been employed. Twenty-five of the thirty-five patients traced had excellent results, six had fair results, and four had poor results.

Maintenance of reduction did not seem to be a problem in the treatment of these patients. Our study indicated that older patients seemed to have residual pain or limitation of motion. The follow-up in this group was accomplished mainly

TABLE IV

DATA ON CASES IN WHICH CLOSED REDUCTION WAS PERFORMED

Case	Age (*Years*)	Sex	Duration of Dislocation (*Days*)	Mode of Treatment	Follow-up* (*Years*)	Functional Result	Late Roentgenographic Findings in the Acromioclavicular Joint	Occupation Before Injury	Occupation After Injury
36	15	M	1	Suspension cast	12	Excellent	Slight upward subluxation; ossification	Student	Truck driver
37	20	M	1	Suspension cast	12	Excellent	Reduced	Farmer	Farmer
38	9	M	1	Velpeau bandage	9	Excellent	Reduced	Student	Student
39	22	M	4	Suspension cast	8/12	Excellent	Reduced	Student	Deputy sheriff
40	57	M	6	Suspension cast	11	Excellent	Reduced	Tavern owner	Retired

* Re-examination in all cases.

by letter or telephone call; we were not able to obtain enough follow-up roentgenograms to make a significant study of late roentgenographic changes. We had the impression, however, that it was the attritional changes in the acromioclavicular joint commonly seen in older patients and the greater tendency of older patients to have post-traumatic periarthritis that contributed to the increased number of fair and poor results in this group.

ANALYSIS OF THE FAIR AND POOR RESULTS OF THE TREATMENT OF COMPLETE DISLOCATIONS

We have based the grading of our end results on function. None of the patients traced with fair results and only one (Case 20) with a poor result have sought further treatment; this indicates that the reported pain or restriction of motion was not serious.

The largest group of patients with results other than excellent were among those treated by fixation of the acromioclavicular joint by wires, screws, or pins (Table II). In Cases 16, 21, and 23 pain appeared to develop secondary to degenerative changes in the acromioclavicular joint. This could have resulted in part from the original trauma and in part from the use of wires across the acromioclavicular joint. Wires transfixing a joint as small as the acromioclavicular joint may contribute to the development of degenerative changes. Loosening and migration of these wires may have contributed to the reported fair results in two cases (Cases 17 and 20).

In Case 20 fixation of the acromioclavicular joint with Kirschner wires was tried first. The wires, however, began to loosen and migrate two weeks after operation. As a result, they were removed earlier than originally planned, and dislocation of the joint recurred. Because of continued pain, the joint was reduced again and held with a screw from the clavicle to the coracoid, and, in addition, the coracoclavicular ligaments were repaired with fascia. In Case 17 the patient was psychotic before and for a period after operation and did not follow instructions. Loosening and bending of the Kirschner wires occurred. We believe that this may have contributed to the pain in the region of the acromioclavicular joint, which, however, was mild.

In seven patients (six followed) treated by a fascial suture passed through drill holes in the acromion and the clavicle to hold the joint in a reduced position, there was one poor result (Case 25). This patient had a low-grade postoperative infection with subsequent development of stiffness of the shoulder. This cleared up in a year, but the result was rated as *poor* because of the delayed convalescence.

In one of the three cases with a fair result after treatment with a coracoclavicular lag screw (Case 35), excessive ossification in the region of the coracoclavicular ligament seemed a possible explanation for the mild restriction of motion. In the other two cases, degenerative changes in the acromioclavicular joint seemed to be a cause of the pain. In one of these two patients (Case 20) the fair result was primarily due to previous failure of fixation of the acromioclavicular joint by the Kirschner wires; in the other (Case 34), treatment with a coracoclavicular lag screw was instituted four months after injury. In retrospect, four months is too long after injury to treat such an injury by this method; the same statement might be applied to Case 35.

Of those treated only by excision of the outer end of the clavicle, one patient (Case 14) had a fair result. This result was rated as *fair* because of slight restriction of motion and pain for which we found no explanation.

EVALUATION OF RESULTS

Anatomical Results

Re-establishment of anatomical relationships, in all the groups analyzed, seemed best accomplished by fixation of the joint with Kirschner wires, a screw, or pin. Anatomical reduction was achieved in all patients so treated, with the exception of one in whom the wires were removed prematurely after they had worked loose and had begun to migrate (Case 20). Although this method did maintain reduction, late follow-up roentgenograms revealed degenerative changes in four of the eight patients so treated. Even more interesting was the development of pain in the region of the acromioclavicular joint in four of these patients before the final follow-up examination.

Coracoclavicular screws were used in seven patients with acceptable functional results on the whole. After removal of the screws two patients had recurrent dislocation of the acromioclavicular joint, and two had moderate subluxations. Roentgenograms in the immediate postoperative period had revealed complete reduction of the dislocated acromioclavicular joints in these patients.

Residual upward displacement was present in all eight patients treated by simple excision of the outer end of the clavicle. In the seven patients treated by excision combined with a supplemental procedure to eliminate this upward displacement of the clavicle, failure to maintain anatomical reduction of the clavicle occurred in all patients. The anatomical results of these combined procedures did not differ from those of simple excision of the distal end of the clavicle.

Strength

Strength was evaluated from direct questioning of the patient and by manual testing of the strength of both shoulders at the time of follow-up examination. None of the patients treated by excision of the outer end of the clavicle complained of weakness at the time of late follow-up. Only two patients (Cases 16 and 20) complained of mild weakness at the time of follow-up, but it was not enough to interfere with work. One patient (Case 25) had considerable weakness of the involved shoulder for one year after operation, but, eventually, this condition disappeared. None of the patients had to change his occupation because of weakness or even because of pain or limitation of motion. The reported changes in

occupation recorded in Tables I through IV were not, in our opinion, related to the injury or subsequent treatment.

COMMENT

The orthopaedist faced with a completely dislocated acromioclavicular joint may choose from a variety of methods of treatment. That the injury is infrequent is apparent from the small number of cases that we have had and others have reported. Our experience has been limited but is sufficient to warrant cautious conclusions.

Fixation of the completely dislocated acromioclavicular joint by wires, screws, or pins, although yielding a good anatomical result, has the disadvantage of possible migration of the wires early in treatment. It is conceivable that this might have been prevented by using threaded wires. Nonetheless, subsequent degenerative changes in the acromioclavicular joint at a later date are complications to be reckoned with. Fascial suture to fix the acromioclavicular joint has the disadvantage of requiring another incision to obtain the fascia.

In our experience the coracoclavicular screw has yielded fair to excellent results when used primarily. However, mastery of the technique is not easy. In the series reported by Kennedy and Cameron a third of the patients had results that were rated as *fair* or *less than fair*. The necessity for later removal of the screw when this method is used is also an objection.

Simple excision of the outer end of the clavicle has yielded satisfactory results in our group of patients. Adding coracoclavicular screw fixation or fascial reconstruction of the coracoclavicular ligaments did not seem beneficial. The residual upward displacement of the clavicle was not disturbing to any of these patients. None of them presented subjective or objective evidence of weakness of the involved shoulder after operation and none had pain or limitation of motion.

For a symptomatic old dislocation of the acromioclavicular joint, we recommend simple excision of the outer end of the clavicle. For fresh injuries, perhaps more consideration should be given to closed treatment. Experience with five acromioclavicular dislocations successfully treated by closed methods does not warrant the recommendation of this method as primary treatment for fresh injuries. However, the experiences of Urist [16,17] and of Stubbins and McGaw with closed methods and our own limited experience lead us to suggest that closed methods be seriously considered before resorting to open operation. If a closed method is selected for primary treatment, and a normal range of painless motion is not restored, simple excision of the outer end of the clavicle can be done at a later date.

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The Hunchback Carpal Bone

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In this increasingly litigious age, it is well to be aware of anatomical variations that can simulate more serious lesions. One such is the os styloideum, termed by the French *carpe bossu* (hunchback carpal bone). This supernumerary carpal bone has long been known to anatomists, who referred to it as the ninth carpal bone [1,3]. It is located at the dorsal side of the tip of the styloid process of the third metacarpal, between the capitate, the trapezoid, and the bases of the second and

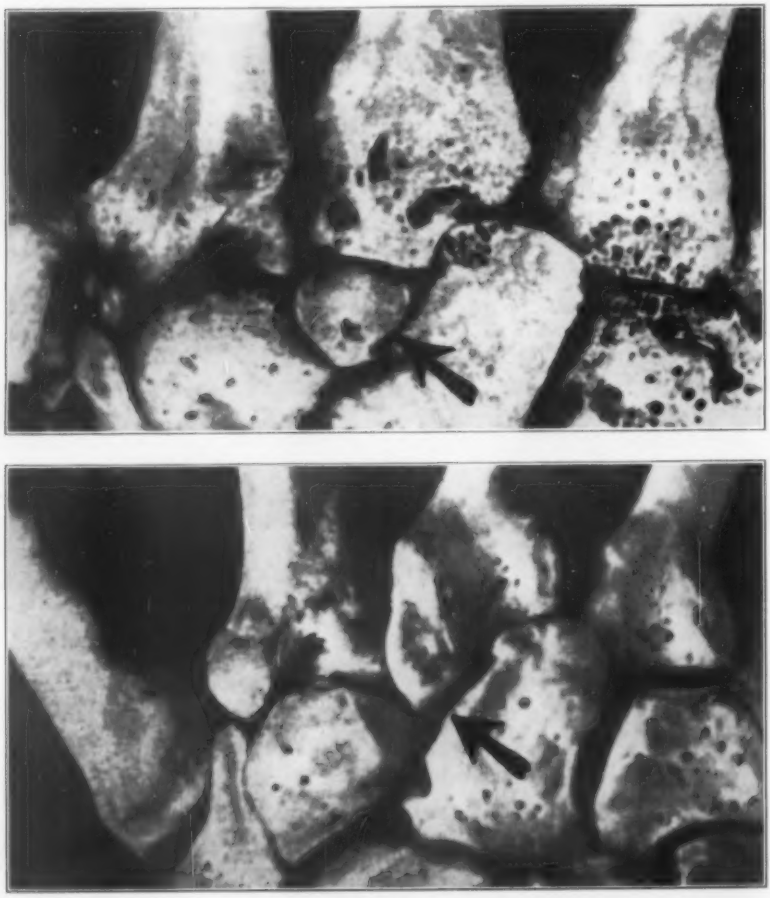

FIG. 1

Os styloideum. Note the coalescence with the base of the third metacarpal in the lower picture. (Reproduced, by permission of the original publisher, Georg Thieme, Stuttgart, Germany, Publishers, from Borderlands of the Normal and Early Pathologic in Skeletal Roentgenology by Alban Köhler. Ed. 10, revised by E.A. Zimmer and translated by J.T. Case. New York, Grune and Stratton, 1956.

FIG. 2
Case 1.

FIG. 3
Case 2.

third metacarpal bones. Zimmer stated that Pfitzner found it present in sixteen of 419 hands examined. Bassöe and Bassöe described it in six of 450 hands examined roentgenographically and were apparently the first to show that *carpe bossu* disease was actually a symptomatic os styloideum. It is best seen in a lateral roentgenogram, and may be obscured on an anteroposterior roentgenogram. It is most often found as a separate ossicle, although Köhler remarked on the pronounced tendency of the os styloideum to coalescence, especially with the second and third metacarpals (Fig. 1).

The os styloideum may often be asymptomatic, and its presence will be discovered accidentally. Symptoms may develop, however, especially after injury to the hand or after heavy labor. Characteristically, the patient presents with a complaint of pain in the region of the dorsum of the second and third metacarpal joints and a tender bone mass. There may be associated edema and redness of the overlying skin.

Once the nature of the symptomatic os styloideum is recognized, if symptoms seem to warrant it, the hand and wrist may be immobilized for three to four weeks. For persistent symptoms, surgical excision of the os styloideum has been recommended[1]. However, Carter, who described this condition as "carpal boss" in

1941, concluded that patients with this condition should not be operated on because of the recurrence of a bone mass after surgery in two of his cases. He further stated that the etiology was unknown and was apparently unaware that the carpal boss was actually the os styloideum. Recently, Lamphier reported three cases of what he also termed *carpal boss*. The bone prominence was removed in each instance, and symptoms were relieved. This author also stated that the etiology of this condition was unknown and did not recognize the presence of an os styloideum.

Two cases are briefly presented for illustration:

Case 1. A.M., a medical student, twenty-four years old, had noted a hard, slightly tender swelling at the dorsal aspect of the base of the right third metacarpal one month before examination. There was no recollected history of injury, and the mass had not increased in size. Roentgenograms showed a typical os styloideum, as well as a separated ulnar styloid tip, which probably represented a persistent separate ossification center, as there was no history of remote or recent trauma (Fig. 2). The patient elected not to have a cast applied. On follow-up eight months later, he stated that his hand was asymptomatic except for a slight ache after excessive use of the wrist, such as in playing golf.

Case 2. J.B., a machine operator, thirty-seven years old, had had his left hand pinned to the floor when a heavy box fell on it. Roentgenograms made at that time were interpreted as showing a fracture of the base of the third metacarpal, and a cast was applied for three weeks (Fig. 3). After removal of the cast the patient continued to complain of ache and discomfort in the same area with use of the hand. Six months later he again struck the back of the left hand, and local swelling and pain developed. At this time a slightly tender bone prominence at the base of the third metacarpal was noted. Roentgenograms made at this time were interpreted as showing an old chip fracture. As complaints persisted, surgical excision of the bone prominence was done. At operation, the bone mass seemed to extend from the base of the third metacarpal bone, and a separate bone ossicle was not identified. The bone mass was removed with an osteotome, but the nature of the cleft visible on the roentgenogram was not determined.

One month after surgery, there was still some local tenderness, but the patient was thereafter lost to follow-up, and the final result is not known.

CONCLUSION

Recognition of an os styloideum may prevent the embarrassment of its being mistaken for a more serious entity, such as fracture or tumor. In symptomatic cases, surgical removal of the prominence may be done, although the reports as to the lasting value of this are conflicting.

NOTE: The author wishes to thank Dr. J. George Furey for permission to report Case 2.

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Metaphyseal Cortical Defects in the Tubular Bones of Growing Children

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Metaphyseal cortical defects are one of the common abnormalities found on the roentgenograms of the tubular bones of growing children. First described by Sontag and Pyle in a review of the roentgenograms of the femora of children examined at the Fels Research Institute, these defects were also described by Caffey [2], Hatcher, and Aegerter and Kirkpatrick. They were not mentioned in Köhler-Zimmer's extensive review of normal variations in bone.

The group of 101 subjects described by Sontag and Pyle consisted of fifty-four girls and forty-seven boys. Twenty-two per cent of the girls and 53 per cent of the boys had metaphyseal cortical defects, even though this study was limited to defects present in the femur. In Caffey's study [2] of 154 children, including seventy-nine boys and seventy-five girls, he found that thirty-three (42 per cent) of the boys showed defects and twenty-three (31 per cent) of the girls showed defects. Hatcher's review included twenty-eight male and seventeen female subjects with defects.

METHOD OF STUDY

It was the purpose of this study to review the roentgenograms of a group of children, who have been followed regularly at the Fels Research Institute, with particular reference to the incidence and life history of these roentgenographic changes. An attempt was made to determine if there had been any change in the incidence of these defects since the first report. None of the children in the study of Sontag and Pyle was included in the present study, and, in contrast to the study of Sontag and Pyle that concerned only the femur, the present study included all the long bones of the lower extremities of which roentgenograms were available.

In addition to the children included in the present study, many of their siblings were also reviewed as a separate group to determine the familial incidence of these defects.

The character of the population from which these children came had not changed substantially since the first study of Sontag and Pyle. The socio-economic distributions were about the same. The population was Caucasian in composition and consisted of farmers and tradesmen in moderate circumstances.

Despite the similarities in the populations of the two studies, many social changes had taken place during the interval between the two studies. A war had intervened, and changes in nutrition and ways of life had taken place that may have influenced the incidence and characteristics of the defects.

In the present study the group consisted of children who were born after 1937 and before 1953. These children repeatedly underwent complete pediatric examinations. Anthropological measurements were made in which the child's weight, length, and chest, skull, and calf measurements were taken routinely. Each child was examined roentgenographically at birth and at one month, three months, six months, nine months, and one year of age. Thereafter, roentgenograms

TABLE I

FAMILIAL INCIDENCE

Family	No. of Siblings in Family	No. of Children in Review	No. of Children with Metaphyseal Cortical Defect	Sex M	Sex F
Bra	1	1	1	1	0
Sto*	3	2	2	1	1
Nee	7	5	3	2	1
Den	2	2	2	2	0
Cop	3	3	1	1	0
Lor	1	1	1	1	0
Ree	1	1	1	1	0
Wal*	4	2	2	2	0
Sho	2	2	2	1	1
Han	1	1	1	0	1
Ast	2	1	1	1	0
Tre	1	1	1	0	1
Odi	3	2	1	0	1
Bea	5	4	3	1†	2
Kin	4	3	1	0	1
Rom	1	1	1	1	0
Str	1	1	1	1	0
Dun	4	4	2	1	1
Swa	2	2	1	1	0
Clo	5	3	1	0	1
Kin	3	3	1	0	1
Car	3	3	2	1	1
Bar	1	1	1	1	0
Pav	2	2	1	1	0
App	4	3	1	1	0
Fin	3	1	1	1	0
Sni	4	3	1	0	1
Geg	2	2	1	0	1
Par	1	1	1	1	0
Fin	4	2	1	0	1
Pil	3	2	1	0	1
Cat	1	1	1	0	1

* One of these patients was described by Sontag and Pyle but was not included in this review of metaphyseal defects.

† Twin.

were made at half-yearly intervals until the child reached the age of eighteen years. Included in this examination were soft-tissue roentgenograms of the extremities and roentgenograms of the skull, teeth, and extremities. The latter included an anteroposterior roentgenogram of the left lower limb, invariably, and a similar roentgenogram of the right lower limb, frequently. Lateral roentgenograms of the extremities were often available, but not uniformly. Some lateral and anteroposterior roentgenograms of the knee joint also were made. Whenever possible, the defects were measured with a Fisher caliper. The measurements were in millimeters, recording the greatest length and width of the defects. A special posture roentgenogram was also made of the children from the age of two and one-half to eight and one-half years, inclusive. Whenever there was uncertainty as to the presence of a defect on an anteroposterior roentgenogram, this additional material was used as a check.

These defects have been called cysts by Sontag and Pyle, fibrous defects by Caffey [2] and Hatcher, desmoids by Kimmelstiel and Rapp, and subperiosteal defects by Aegerter and Kirkpatrick. They have been distinguished from non-osteogenic fibromata because they fluctuate in size from time to time, grow smaller, and eventually disappear spontaneously and do not extend across the mid-line of the bone involved or invade the medullary cavity.

TABLE II

AGE AT ONSET AND DURATION OF METAPHYSEAL CORTICAL DEFECTS

	No. of Defects First Apparent at Age (in Years):								Time from Appearance to Disappearance (*Years*)
	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	Totals	
	1	3						4	1.0
					2	1		3	1.5
	1	2	2					5	2.0
			1		2			3	2.5
			1	2				3	3.0
		5	4	1	1			11	3.5
	1	1		2	1			5	4.0
	2	1	4				1*	8	4.5
		1					1*	2	5.0
		2						2	5.5
	1							1	6.0
			1*					1	11.0
Totals:	6	15	13	5	6	1	2		
Average Years That Defect Persisted:	3.67	3.27	4.04	3.50	2.58		4.75		

* Still present at the time of writing.

The metaphyseal cortical defects included in this series were radiolucent areas found incidentally at the growing ends of the long bones. These defects did not appear until late in the second year of life; they caused no symptoms and disappeared without treatment. Because of their situation in the cortex, often in the superficial cortex, the cortical gap was not visible unless the roentgenogram was made with the limb in optimum position to show the defect in profile.

FINDINGS

One of the first signs of a developing defect was thickening of the trabeculae in the region of the metaphysis. As the study progressed, it was found that, whenever a metaphyseal cortical defect developed, earlier roentgenograms showed a pre-existing thickened trabecular structure at the site of the defect. In one instance, a thickened trabecular structure was noted in one portion of the metaphysis, and subsequent roentgenograms revealed a metaphyseal defect somewhat removed from the trabecular thickening. This occurred in the head of the fibula, and the trabecular defect preceded by two years the metaphyseal cortical defect.

As growth proceeded, all metaphyseal defects were found to be farther away from the epiphyseal cartilage. No trabecular thickening or subperiosteal irregularity that did not become increasingly separated from the epiphyseal cartilage was included in this series. The largest of the defects encountered was 2.5 centi-

FIG. 1

FIG. 2

Fig. 1: Roentgenogram made when the patient was three and one-half years old.
Fig. 2: Roentgenogram made when the patient was five years old.

FIG. 3

FIG. 4

Fig. 3: Roentgenogram made when the patient was five and one-half years old.
Fig. 4: Roentgenogram made when the patient was ten years old.

meters in length and 1.5 centimeters in breadth. The smallest ones usually were longitudinally oriented and ellipsoidally shaped, but several of them had appeared as groups of ellipsoids piled one on top of the other. From time to time, the larger groups of ellipsoids coalesced, or septa would appear between some of them.

In some of the serial roentgenograms, the defects seemed to have disappeared temporarily and then to have reappeared. This temporary disappearance was seen particularly when the defects were located close to the periosteal surface of the bone. This apparent disappearance was found to occur when the roentgenograms were made with the limb in a position that failed to bring the lesion into profile. This was well demonstrated in some of the children who had had two roentgenograms on the same day—one showing the defect, and the other failing to do so. Failure of the roentgenogram to reveal a defect was particularly common with the small or apparently small defects that in certain positions of the limb

were obscured by the adjacent thick cortical layer. Slight differences in positioning also tended to cause rather significant changes in the shape of individual defects from one examination to another, but, in the main, the defects tended to remain circular or ellipsoid.

In this study there were 151 children, the siblings of seventy-five families; eighty-eight were boys and sixty-three were girls. Twenty-four boys and eighteen girls had defects. The incidence in this study was 27 per cent in boys and 29 per cent in girls, which was much lower than in the first Fels study, in which the incidence was 53 per cent in the boys and 22 per cent in the girls. The children in this present study included two sets of triplets and three sets of twins (fraternal). No defects were found in the triplets; one lesion was found in a twin. Two of the siblings of this twin had cortical defects. Two brothers had similar cortical defects that appeared at the same age, were the same size and shape, and were located in the same position.

Fig. 5: Roentgenogram made when the patient was fourteen years old. (The defect was still present when the patient was fifteen years old.)

FIG. 5

The familial incidence apparent in this second study was not noted in the first series. The number of siblings in each family, the number of siblings studied, and the number with defects are shown in Table I. In the families in which one child had a defect, nearly 50 per cent of the siblings also had defects.

The ages at which these lesions appeared are shown in Table II. No lesions were found in children under the age of two years. In two children the defects did not appear until the children were between eight and nine years old. Twenty-eight (58 per cent) of the forty-eight lesions appeared when the children were between three and five years of age. There was no correlation between the size of the defects and the age at which they appeared.

The duration of the lesions (Table II) observed in this series ranged from one to eleven years. One defect, which appeared when the child was four years of age, was still visible eleven years later when the child was fifteen (Figs. 1 through 5), and the two defects (in two children) that appeared when each child was between the ages of eight and nine years were still present four and one-half and five years later. These defects, therefore, lasted no longer than those in the series of Sontag and Pyle, in which the defects were observed to persist for an average of twenty-nine months.

In no instance were there any symptoms that could be attributed to these defects.

CONCLUSION

Metaphyseal cortical defects are a common disturbance of ossification in children and tend to occur as commonly in boys as in girls. Their incidence is about 27 per cent in the total population, as estimated from this series. A definite familial incidence was established.

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Traumatic Dislocation of the Hip in Children

A Report of Seven Cases and Review of the Literature

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It is the purpose of this paper to report seven cases of traumatic dislocation of the hip in children ten years of age or less, and to review briefly some of the opinions and observations of previous writers on this subject.

In 1924, Choyce collected from the literature fifty-three cases of traumatic dislocation of the hip in children and added five unpublished hospital case reports and a case of his own. Despite poor follow-up in most of these cases, Choyce found four cases in which secondary changes occurred in the hip within one to two years after injury— in one other case the length of time was not stated.

Tables I and II indicate the length of follow-up and the incidence of complications in the cases with adequate data reported in the literature.

Table III summarizes all cases of traumatically dislocated hips in this age group admitted to Vanderbilt University Hospital and seen in various private clinics in Nashville, Tennessee, over a period of thirty years. The patients' ages at the time of dislocation ranged from two to ten years.

DISCUSSION

There are too few recorded cases of traumatic dislocation of the hip in children for significant statistical analysis. However, certain trends are apparent that I believe suggest tentative recommendations for the treatment and postoperative management of this injury.

Early closed reduction by gentle manipulation under general anesthesia is desirable, but open reduction may be required for dislocations that have been un-

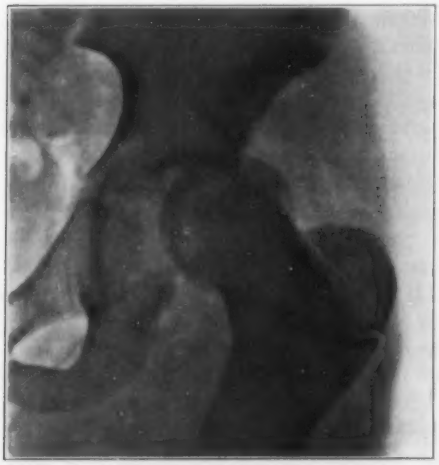

FIG. 1-A

FIG. 1-B

Fig. 1-A: D. L., Case 2. Admission roentgenograms made in February 1954, revealing a posterior dislocation of the left hip.

Fig. 1-B: Six years after reduction (March 1960). The hip appears normal.

TABLE I

DATA ON PERSONAL CASES AND CASES WITH FOLLOW-UP REPORTED IN THE LITERATURE

Observer	No. of Cases	No. with Follow-up	Length of Follow-up	No. of Complications
Choyce (1924)	59	37	Few days to 4 yrs.	9*
Clarke (1929)	1	1	9 mos.	0
Elmslie (1932)	1	1	8 mos.	1
Glynn (1932)	2	1	11 mos.	0
Haines (1937)	1	1	4 mos.	0
Goldenberg (1938)	1	1	3 yrs.	1
Banks (1941)	1	1	6 yrs.	1†
Thompson and Epstein (1951)	17	8	1 to 19 yrs.	1‡
Mason (1954)	1	1	10 mos.	0
Watson-Jones (1957)	1	1	5 yrs.	1
Litton and Workman (1958)	1	1	3 yrs.	1
Pennsylvania Orthopedic Society (1960)	30	16	6 mos. and more	22¶
Freeman (1961)	7	6	1 to 10 yrs.	3

* Of the complications listed by Choyce, a certain number were secondary to the therapy rather than to the original injury; the most obvious of these have been omitted.

† Banks included only one patient because the other young patients were believed to have approached skeletal maturity at the time of dislocation.

‡ The only complication noted by Thompson and Epstein occurred in a patient who sustained a fracture of the head of the femur at the time of dislocation.

¶ Several complications may have been present in one patient; the total number of patients with any complication is not stated.

recognized for days or weeks. Traumatic dislocation of the hip is easily overlooked, perhaps because it is rare and such slight trauma may produce the injury.

A spica cast is adequate immobilization to prevent recurrent dislocation and permits the patient to be cared for at home. It also assures non-weight-bearing. Immobilization in the cast should be continued for four to six weeks, or until soft-tissue healing is complete and the synovial irritation has completely subsided. Longer immobilization in plaster may be indicated if the patient's age or environment is such that non-weight-bearing cannot otherwise be assured.

The ideal time to resume weight-bearing has not been established, but, since in some of the reported cases there was evidence of synovial irritation many weeks after injury, it would appear that weight-bearing should not be attempted for a minimum of two to three months. If symptoms of synovial irritation recur after the resumption of weight-bearing, the patient should again be placed on non-weight-bearing status, and roentgenograms should be obtained to determine whether secondary changes are present. If no changes are detected, weight-bearing should be resumed after three or four weeks. The parents should be warned initially that the onset of complications may be delayed for several months, and the patient should be under observation for at least one year after injury.

Any conclusions as to prognosis after this injury must be tentative, based on the few cases available with adequate follow-up. From the data at hand, it appears that the severity of the trauma producing the dislocation is of little significance in prognosis. In the majority of the reported cases with complications, the instigating trauma was mild. Delay in reduction, unsuccessful closed reduction, and recurrent dislocation seem to be reasons for a guarded prognosis. The

TABLE II

DATA ON COMPLICATIONS

Reporter	Age of Patient (*Years*)	Sex of Patient	Mode of Injury	Delay before Reduction	Type of Reduction	Postoperative Immobilization	Period of Non-Weight-Bearing	Type of Complication	Time Lapse before Complication Recognized
Banks	12	M	?	?	Closed	Spica	?	Perthes' disease	15 mos.
Choyce	6	M	Fall	1 wk.	Closed	None	Less than 6 wks.	Minor roentgenographic changes in acetabulum and head; range of motion normal	8 mos.
Courtillet and Lombard (cited by Choyce)	3½	M	?	1 wk.	Closed	?	?	Recurrent dislocation	10 days
Elsmlie (1919; cited by Choyce)	4	M	?	8 days	Closed	?	?	Pseudocoxalgia	1 yr.
Elmslie (1932)	7	F	Caught in hay lift	1 wk.	Closed	3 wks.	3 wks.	Coxa plana	8 mos.
Endlich (cited by Choyce)	9	M	?	9 wks.	Open	?	?	Recurrent dislocation	2 mos.
Gerstner (cited by Choyce)	8	M	?	7 wks.	Open	?	?	Recurrent dislocation	1½ mos.
Goldenberg	10½	M	Automobile accident	1 wk.	Closed	Spica cast	3½ wks.	Perthes' disease	15 mos.
Higgins (also included in Choyce's article)	8	M	Fall	3 wks.	Closed	Spica cast	2½ wks.	Recurrent subluxation	1½ yrs.
Höfliger (cited by Choyce)	5½	F	?	4 mos.	Open	?	4 wks.	Suppuration	?
Litton and Workman	5	M	Struck by automobile	8 days	Closed attempted; open 1 mo. later	Cast, 2 mos.; ischial brace, 4 mos.	6 mos.	Irregularity of head; limitation of motion	6 mos.
Pennsylvania Orthopedic Society							Average: 18 wks.	Limitation of motion, 5 pts.; residual pain, 3 pts.; residual limp, 4 pts.; femoral-head deformity, 5 pts.; residual shortening, 3 pts.; aseptic necrosis, 2 pts.	6 mos. to 1½ yrs.
Rehbein (cited by Choyce)	8	M	?	Few hrs.	Closed	None	2½ wks.	Perthes' disease	1 yr.
Spenzer (cited by Choyce)	8	M	?	?	Closed	?	?	Recurrent dislocation	5 mos.
Thompson and Epstein	Between 6 and 10	M	Automobile accident	24 hrs.	Closed	Abduction frame, 3 mos.	3 mos.	Exostosis of head of femur	13 yrs.
Volkmann (cited by Choyce)	13	M	?	13 wks.	Manipulation failed; femur fractured	None	?	Ankylosis	?
Watson-Jones	5	?	Not stated	Not stated	Closed	Not stated	Not stated, but prolonged	Perthes' disease	4 mos.

TABLE III

DATA ON PERSONAL CASES

Patient	Age (*Years*)	Sex	Mechanism of Injury	Type of Dislocation	Time Lapse before Reduction	Type of Reduction	Immobilization	Period of Non-Weight-Bearing	Length of Follow-up	Complications	Remarks
N. A. P.	4	F	Fall	Posterior	3 wks.	Closed	Spica cast, 1 mo.	1 mo.	2½ mos.	?	Patient lost to follow-up
D. L.	10	M	Fall	Posterior	2 hrs.	Closed	Spica cast, 3 wks.	3½ mos.	6 yrs.	None	Patient participates in contact athletics; no clinical or roentgenographic difference in two hips
P. A. C.	7	F	Automobile accident	Posterior	3 mos.	Open	Spica cast, 2 mos.	2 yrs.	10 yrs.	Aseptic necrosis	Normal hip clinically; original roentgenograms show questionable fracture of acetabulum
K. D.	3	M	Fall	Postero-inferior	3 hrs.	Closed	Left limb in X-bar, 4 wks.	1 mo.	5 yrs.	None	Symptoms 2 mos. after injury; no residual signs
T. S.	2	M	Fall	Posterior	4 hrs.	Closed	Spica cast, 6 wks.	2½ mos.	1 yr.	None	No symptoms
K. H.	5	F	Fall	Posterior	3 hrs.	Closed	Spica cast, 3 wks.	2 yrs.	3 yrs.	Aseptic necrosis	This was recurrent dislocation, 3 mos. after first episode in Aug. 1954; initial reduction without anesthesia before roentgenograms made; activity restricted for about 2 wks.; in Mar. 1955, about 5 mos. later, roentgenographic changes compatible with aseptic necrosis of femoral head present
F. F.	10	M	Fall	Posterior	1 hr.	Closed	Spica cast, 4 wks.	3 mos.	6 yrs.	Persistent synovitis	Weight-bearing 3 mos. after injury, but hip became painful; non-weight-bearing resumed; bearing of weight after 10 days with same result; roentgenograms 4 mos. after injury believed to show early changes of aseptic necrosis; indefinite period of non-weight-bearing was advised; parents dissatisfied; did not return; patient examined 6 yrs. after injury; hip appeared normal both clinically and by roentgenogram

FIG. 2-A

FIG. 2-B

Fig. 2-A: P.A.C., Case 3. Initial roentgenograms made in July 1949 reveal dislocation of the right hip. In addition, there may be an associated fracture of the posterior lip of the acetabulum.
Fig. 2-B: Roentgenograms made in December 1949 show cystic changes within the head of the affected femur and irregularity of the articular surface of the head.

FIG. 2-C

Roentgenograms made in April 1953, approximately four years after reduction, show almost complete reversal of changes and restoration of the normal architecture of the head.

ages of the patients with complications ranged from four to thirteen years, with an average age of seven and one-half years. Possibly, the prognosis is better in the younger patients who sustain this injury. The average time lag before recognition of complications was slightly over ten months.

SUMMARY

Seven cases of traumatic dislocation of the hip in children have been presented together with a brief review of the literature. The care, prognosis, and complications of this injury have been discussed, and tentative recommendations regarding initial treatment and postoperative regimen have been advanced.

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Delayed Bone Transplantation*†

An Experimental Study of Early Host-Transplant Relationships

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The value of free bone transplants in osteosynthesis of fractures, arthrodeses, and orthopaedic reconstructive procedures has been established by experimental and clinical observations. Although much has been learned about the physiology of bone transplantation, many fundamental questions remain unanswered. In clinical orthopaedic surgery, the practical significance of important experimental observations is still unknown.

When a bone transplant is to be employed, the type of bone used should be evaluated on the basis of its architectural and immunological characteristics. Architecturally, the transplant supplies a surface along which new bone may grow; the transplant may thus permit the bridging of defects that ordinarily might remain unhealed. Cancellous transplants have large surface areas available for the growth of new bone [1,14,18,20,22,30]. This asset, however, is often sacrificed in favor of the more rigid fixation and internal strength provided by cortical grafts. Immunologically, autogenous transplants are tolerated better than homogenous and heterogenous grafts [6,9,10,37], although the mechanism responsible for the lesser incorporation of the homogenous and heterogenous transplants is not well understood [11,12,13,16].

Conflicting opinions exist regarding the other roles played by the transplant. Experimental evidence suggests that the presence of a bone transplant adds impetus to osteogenesis by induction [5,7,28,29,35,46]. These experiments, for the most part, involved implantation of transplants into skeletal muscle and the anterior chamber of the eye. Since these tissues are not normally osteogenic, the physiological significance of bone induction under these conditions is questionable. Apparently, transplanted cellular elements are capable of occasional survival [26,34,38]; perhaps actual physical migration of cells from the donor transplant into the host tissues may also occur [4], but the clinical importance of these observations has not been determined.

A notable attempt to potentiate the effect of a bone transplant was the "os purum" developed by Orell. In his experiments, newly formed bone, produced by subperiosteal transfer of boiled and granulated bone fragments, constituted a "delayed bone transplantation".

Most experiments on bone transplantation investigated the relative merits of different types of donor material [2,3,21,23,25,27,36,37,40,43,44,45]. Although the clinical orthopaedic surgeon is well aware of the importance of careful preparation of the host site in reparative surgery, little attention has been paid to the condition of the transplant bed, and few studies have focused on the role of the bed in the incorporation of the transplant [47].

The present investigation is a preliminary histological study of the host bed and its response to an autogenous-bone transplant during the earliest stages of incorporation of the graft. The response to autogenous transplants in freshly

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prepared bone defects has been compared with the response to transplants inserted at different periods of time after the defect was created. In these delayed bone transplantations, the grafts were placed in beds in various stages of early healing, ranging from hematoma to undifferentiated cellular invasion to early procallus. More detailed experiments are in progress, using more carefully controlled defects in the ilium to study the healing of defects and the incorporation of fresh and delayed transplants by histochemical techniques.

When a transplant is placed into a newly created defect, it is surrounded immediately by a hematoma and eventually by an organizing blood clot. The early healing response of an acute wound is evoked with the invasion of cells derived from cellular elements in the bone and soft tissue bordering on the fracture or bone defect [15,18,19,29,45]. A lapse of from one to two weeks occurs before there is significant invasion by new blood vessels and the restoration of a blood supply for the transplanted bone. During this period before vascular ingrowth, the graft usually becomes necrotic, although under ideal experimental conditions surface cells of the transplant may occasionally survive and grow [2,24,33,39]. Knowing this sequence of events, we reasoned, that if a transplant were introduced into a defect after the hemorrhage and the inflammatory response were over and the bed was occupied by vascular proliferating undifferentiated tissue, the environment might be more favorable for the survival and early incorporation of the transplant and the induction of new-bone formation. The concept of timing of the graft was considered and an attempt was made to determine the optimum age of the bed for transplantation.

METHODS

Forty-one male and female rabbits of the chinchilla or New Zealand breed, weighing between 2.5 and three kilograms, and thirteen mongrel dogs, weighing between nine and thirteen kilograms, were used as experimental animals. The host site was a defect (created by resecting a segment of the ulna) 0.5 centimeter in length at approximately the junction of the middle and lower thirds of the ulna. The defects were created in the rabbits with a double-action bone cutter and in the dogs with a motor saw. In creating these defects the bone was resected subperiosteally. In the rabbits, basal anesthesia with nembutal was supplemented by ether. In the dogs, intravenous nembutal sufficed. No immobilization was used and each animal received 300,000 units of procaine penicillin daily for two days after each operation.

Preliminary Preparation of the Host Bed

In the rabbits, at the first operation, a defect 0.5 centimeter long was made in the left ulna and the wound was closed. At a second operation—four days later in nine animals, seven days later in eight animals, and ten days later in nine animals—an incision was made over the iliac crest and a block of bone was removed. This was divided into two equal portions, each consisting of outer cortex and subjacent cancellous bone and measuring 0.3 centimeter square. One fragment was transplanted into a freshly prepared 0.5 centimeter defect in the right ulna, similar to the one previously prepared in the left ulna; the other fragment was transplanted into the soft tissues within the bed of the previously created defect on the left. The defect on the left was approached surgically through a skin incision made 0.5 centimeter away from the healing wound. The previous surgical approach through the deeper tissues was easily identified and the tissues were spread by blunt dissection, uncovering the bone defect. At four days the defect in the ulna contained purplish clot. By seven days, much of the clot had

been absorbed and a friable vascular tissue lay between the bone ends; at ten days this tissue had become denser, firmer, whiter, and less vascular. The graft could be thrust gently into the soft tissues in the bone defect at four and at seven days, but at ten days it was necessary to incise the denser tissue to insert the transplant. The small amount of bleeding and ooze that occurred during this procedure was controlled by gentle pressure with a gauze sponge. The animals were sacrificed at varying intervals during the first two to three weeks after operation. The behavior of the transplants in the fresh and delayed beds in each animal was compared in sections stained with hematoxylin and eosin.

In the experiments in dogs, 0.5 centimeter long defects, ten days old in six animals and two weeks old in four animals, were used as host sites. At ten days the healing tissues in the defect were similar in appearance to those in the rabbit at one week. At two weeks they had increased in density and were comparable to those in the ten-day-old rabbit bed. The dogs were sacrificed two weeks after transplant and sections were prepared and stained with hematoxylin and eosin.

In the control experiments on seven rabbits bilateral defects 0.5 centimeter long were created, but no graft was inserted.

Preliminary Preparation of the Transplant

In previously reported experiments[41] free callus transplanted to fresh defects in rabbits was found to undergo necrosis, as did fresh transplants of iliac bone. In the present experiments, with eight rabbits and three dogs, young callus with its attached parent bone was used as donor material. At the first operation, when a defect similar to those in the experiments just mentioned was made in the left ulna, a longitudinal osteotomy along the crest of the ilium was also performed, extending down through the central cancellous portion. The outer iliac cortex was then pried away from the inner ilium, creating a greenstick fracture of the outer cortex and leaving a space about 0.3 centimeter wide between the cancellous surfaces. This space was maintained by a small stainless-steel wedge inserted between the two surfaces of bone at the base of the osteotomy. At the end of seven days the ilium was removed and a fragment about 0.3 centimeter square, consisting of cortical bone with subjacent cancellous bone and attached callus, was transplanted to a freshly prepared defect in the right ulna and to the previously prepared one-week-old bed in the left ulna. Animals were sacrificed after the first and second week and sections were prepared and stained with hematoxylin and eosin.

FINDINGS

When autogenous transplants of iliac bone and of iliac bone with attached callus were placed in fresh defects, the grafts were completely surrounded by blood clots; they all became necrotic. When studied one and two weeks after transplantation there was no evidence of viability or proliferation of the cellular components of the transplanted tissue. However, as in the control defects, where no graft was employed, there was an early response of undifferentiated cells arising from the endosteal and periosteal components of the host bone. At the end of one week, cartilage and fibrous callus, as well as early new bone, had begun to invade the defect from the cut surfaces of the host bone. After seven days of residence in a fresh bed, the transplant, which had been placed into the center of the defect, was still surrounded by large amounts of blood clot (Figs. 1-A and 1-B). At the end of two weeks, the transplants lay in a bed of undifferentiated proliferating tissue and the borders of the trabeculae of the transplanted bone were often irregular, the result of osteoclastic activity. Only after two to

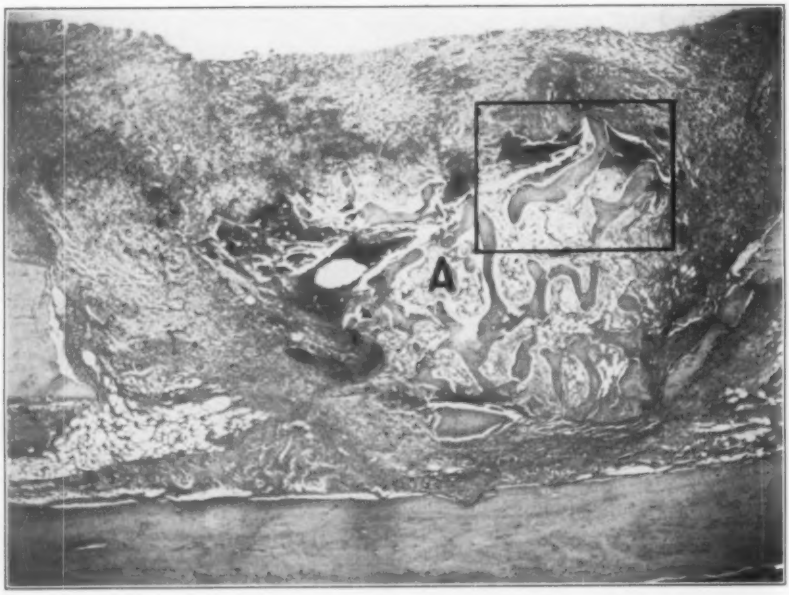

FIG. 1-A

An autogenous iliac fragment, seven days after it was transplanted into a fresh defect in the ulna of a rabbit. The transplant, *A*, is surrounded by a blood clot that is being replaced by invading, undifferentiated tissue from the surrounding bone and periosteum (× 31).

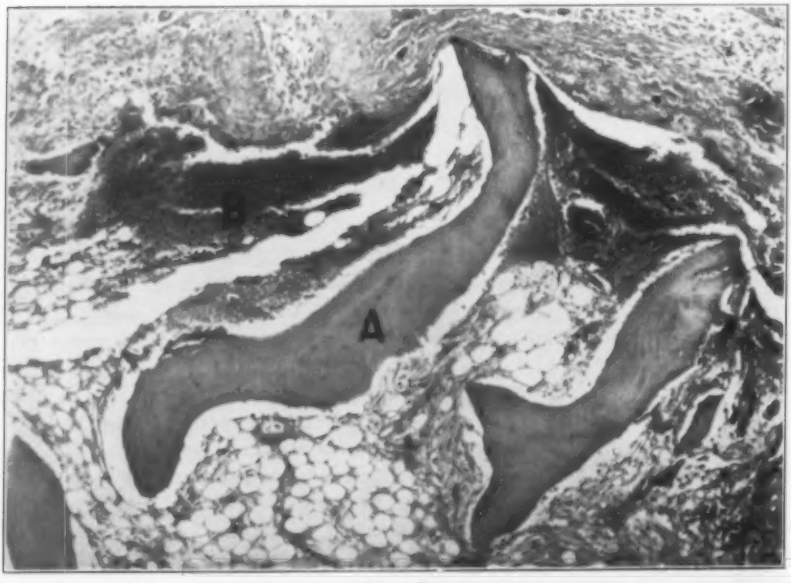

FIG. 1-B

Higher-power view of the area outlined in Fig. 1-A. The necrotic transplanted fragments, *A*, are surrounded by residual blood clot, *B* (× 210).

three weeks did the transplanted fragments in the rabbit become surrounded by callus and early new bone. Fibroblastic proliferation in the bed and massive osteoclastic resorption of the graft occurred in several of the experiments in which transplants were placed in fresh beds. The early healing of the control defects, without transplants, was similar to the healing of defects containing grafts. The presence of the autogenous transplant did not influence the proliferation of undifferentiated tissues or the formation of early callus and bone from the cut ends of the host bone.

Transplantation of Iliac Bone to a Four-Day-Old Bed in the Rabbit

At the end of one and two weeks there was no significant difference between the transplants to a fresh defect and the transplants to a four-day-old bed in the rabbit. The healing process, proliferation of osteogenic tissues, and host-transplant relationships were the same.

Transplantation of Iliac Bone to a Seven-Day-Old Bed in the Rabbit and to a Ten-Day-Old Bed in the Dog

Very small amounts of hemorrhage invariably occurred as a result of the trauma of insertion of the graft into the highly vascular and loosely structured tissue in the seven-day-old beds in the rabbits and in the ten-day-old beds in the dogs, but these hemorrhages were rapidly absorbed and were usually barely evident histologically at the end of one week. As early as seven days after transplantation, large amounts of new bone were often noted forming along the trabecular surfaces of the transplant (Figs. 2-A and 2-B). Introduction of the transplant into the delayed bed did not interfere with the normal repair process in progress within the bed at that time, or with the bone formation occurring from the bone ends or periosteum. In these experiments the transplant was usually rapidly invaded by new bone which grew along the surfaces of the transplant, in advance of the new-bone formation in the rest of the bed. In several instances, both in the rabbits and in the dogs, where grafts were placed in seven-day-old and ten-day-old beds, respectively, osteoid seams were noted to be forming along the trabeculae of the transplant (Fig. 3) or in the intertrabecular spaces (Fig. 4). In these instances, some of the endosteal cells of the transplant appeared to have survived. There were occasional areas of early new-bone formation arising within the undifferentiated cellular bed in the vicinity of, but not in contact with, the grafts. The surfaces and intertrabecular spaces of these grafts exhibited no osteogenic activity (Fig. 5). Successive sections revealed that these areas were not outgrowths of new bone from viable bone in the transplant or from the cut surfaces of the bone of the host. It is suggested that these isolated areas of new bone may have been the result of growth of osteogenic cells that had migrated from the transplant into the bed or the result of an induction phenomenon.

Transplantation of Iliac Bone to a Ten-Day-Old Bed in the Rabbit and to a Fourteen-Day-Old Bed in the Dog

Insertion of an iliac transplant into a ten-day-old bed in the rabbit and a fourteen-day-old bed in the dog necessitated incision of the denser tissues between the bone ends before the graft could be introduced. No viable elements within the transplant or osteoid seams along the surfaces of the grafts were noted in these experiments. Similarly, no new-bone formation was noted in the beds in the vicinity of the grafts in advance of the invasion of cells from the cut surfaces of the bone ends and periosteum. Revascularization of the intertrabecular spaces of the graft in these experiments was slower than that noted in the transplants

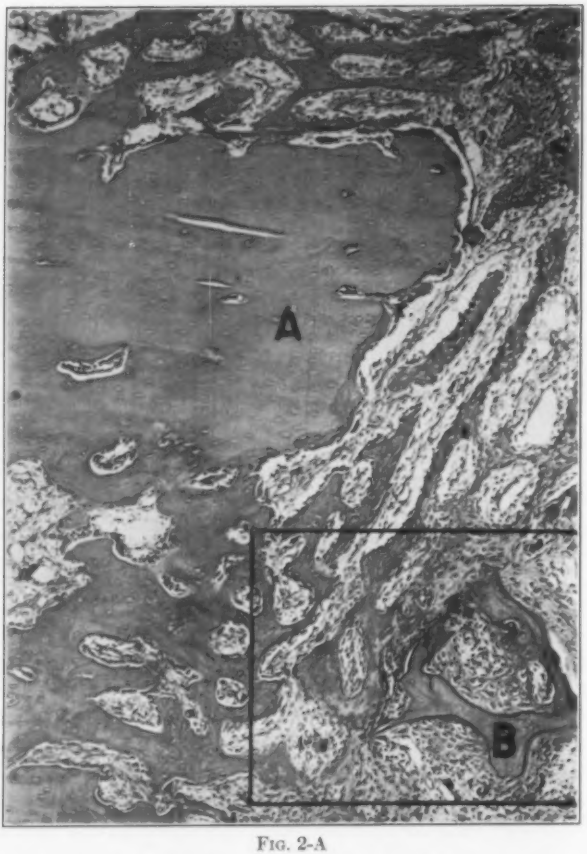

FIG. 2-A

Autogenous iliac graft seven days after transplantation into a seven-day-old delayed bed in the ulna of a rabbit. The undifferentiated cellular tissue of the bed has invaded the intertrabecular spaces of the transplant, *B*. The blood clot has been absorbed. New bone, arising from the host bone ends, *A*, is forming along the transplant surfaces (× 117).

to seven-day-old beds. The cellular elements within the bed at this later stage had been transformed frequently into denser tissues. These surrounded the graft and formed a barrier between it and the invading new bone (Fig. 6). In the instances where a large amount of fibroplasia had occurred within the bed, extensive osteoclastic absorption of the graft was noted and the invasion of the bed by new bone from the periosteum and cut surfaces of the host-bone ends appeared to be retarded.

Transplantation of Iliac Bone with Attached Callus

Transplantation of iliac bone with attached one-week-old callus behaved like the fresh transplants of iliac bone alone. In these experiments, bone-callus fragments were placed in fresh defects in four rabbits, in seven-day-old defects in four rabbits, and in ten-day-old defects in three dogs. Occasional osteogenesis within the undifferentiated cellular tissues of the bed and occasional osteoid seams on the surface of the transplants were noted only in the delayed experiments. Surviving or proliferating elements were never observed within the transplanted

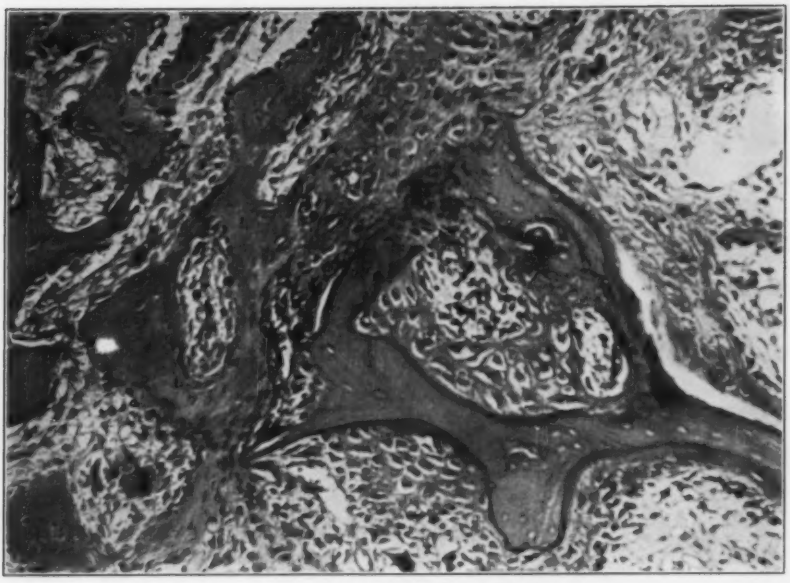

FIG. 2-B

Higher-power view of the area outlined in Fig. 2-A (× 217).

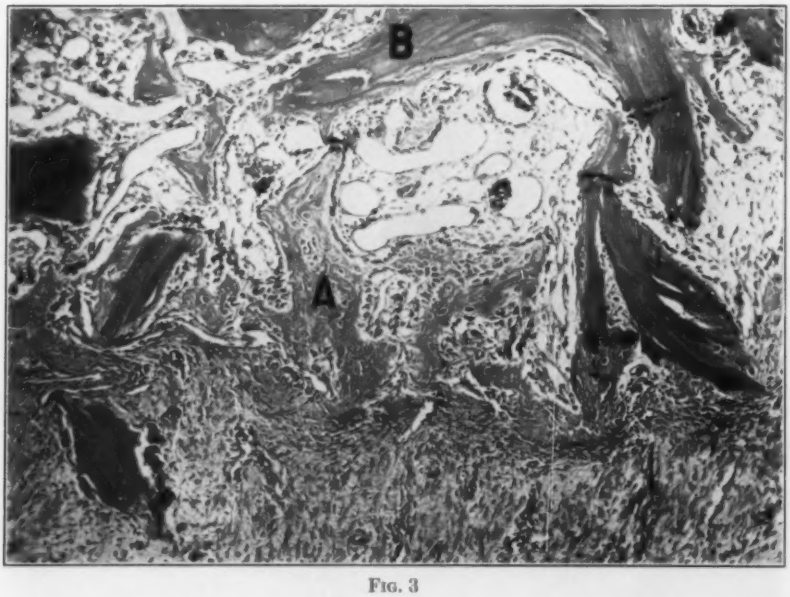

FIG. 3

Autogenous iliac graft seven days after transplantation into a ten-day-old defect in a dog. Osteoid seams are forming in the vicinity of *A* and along the surface of necrotic trabeculae, *B*, isolated within the undifferentiated cellular graft (× 112).

callus fragments. The immature transplanted callus was generally the site of more osteoclastic activity than were the trabeculae of the transplanted iliac bone (Fig. 7).

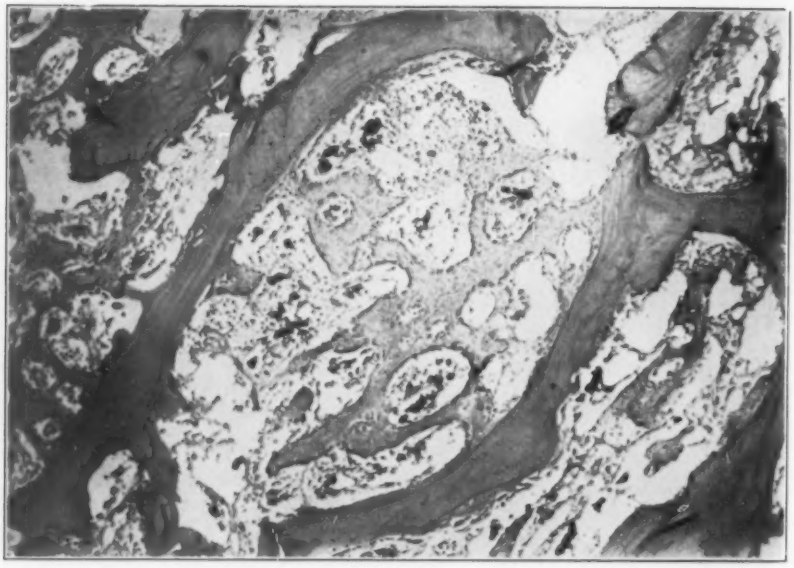

FIG. 4

Autogenous iliac graft seven days after transplantation into a ten-day-old delayed bed in a dog. The necrotic intertrabecular soft tissues have been replaced by loose, vascular, undifferentiated cellular tissues and early new bone (× 217).

FIG. 5

Autogenous iliac graft seven days after transplantation into a ten-day-old delayed bed in a dog. Early osteoid and new-bone formation is noted, *A*, in the vicinity of necrotic transplanted fragments, *B*, isolated within the young, vascular undifferentiated cellular graft bed (× 232).

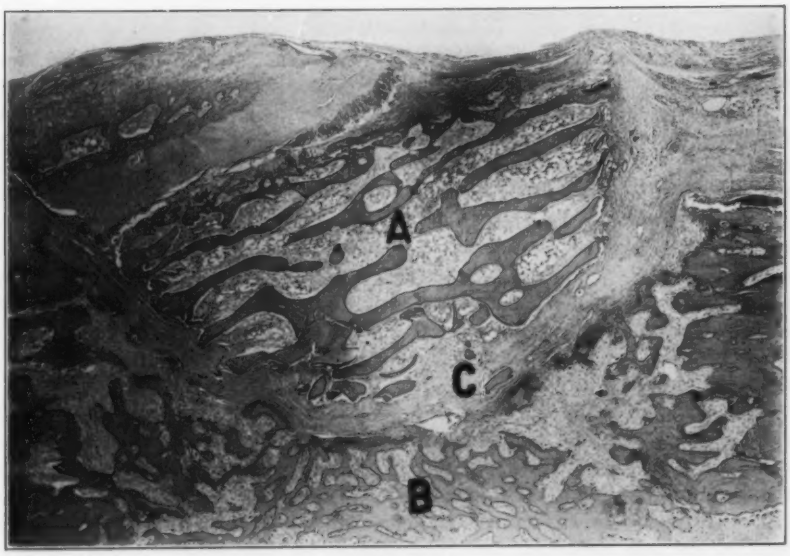

FIG. 6

Autogenous iliac graft two weeks after transplantation into a ten-day-old delayed bed in a rabbit. The transplant, *A*, is necrotic and is separated from the bone that is bridging the defect, *B*, by a dense barrier of connective tissue, *C* (× 25).

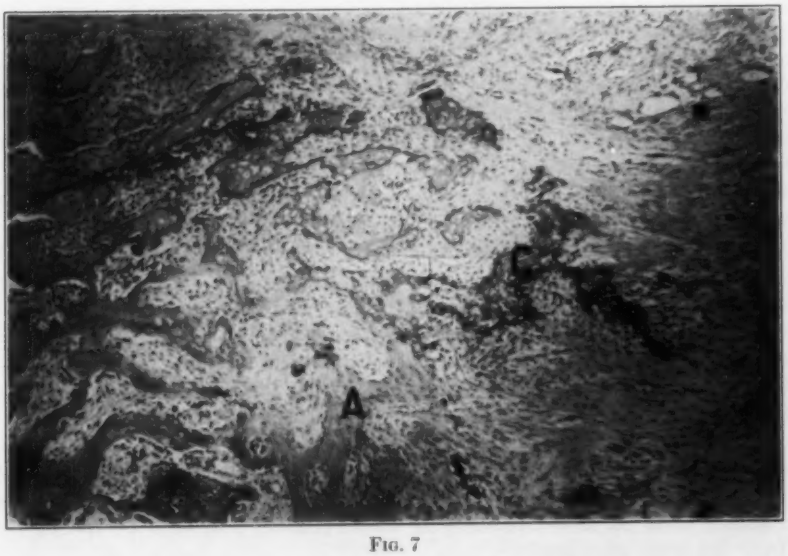

FIG. 7

Autogenous iliac graft with attached one-week-old callus, seven days after transplantation into a seven-day-old delayed bed in a rabbit. All transplant fragments are necrotic, *B*. The transplant has been surrounded and invaded by young, undifferentiated cellular tissue. Although isolated within the bed and distant from the invading new bone from the host, osteoid is beginning to form around the transplant trabeculae themselves and within the bed, in the vicinity of the graft, *A*. The one-week-old callus, *C*, attached to the transplanted bone is necrotic (× 107).

DISCUSSION

In the experiments reported, there was no evidence that any element of bone alone, or of bone with its attached callus, survived when transplanted into a fresh bed, a four-day-old bed, or into the older beds (ten to fourteen days old). No new bone was observed forming within the intertrabecular spaces or within the tissues surrounding the transplant in advance of new bone invading from the periosteum or cut bone ends. In the fresh or four-day-old beds, the grafts lay dormant and became necrotic in the blood clot that had formed between the cut bone ends. Not until the end of the first week did the proliferating cellular elements of the host come in contact with the graft. In the ten to fourteen-day-old beds, the cellular elements within the beds were denser, with the result that when the transplant was introduced at this stage, it was often excluded from the osteogenic complex by the barrier of newly formed connective tissue. The graft then became necrotic and was removed by osteoclasis.

When introduced into a seven-day-old bed in the rabbit and a ten-day-old bed in the dog, however, the transplant was apparently in an environment more favorable for new-bone formation. Rapid contact was established between the transplant and the undifferentiated cellular elements of the bed and there was early invasion of the intertrabecular spaces of the transplant by the cellular tissues of the bed. Although the trabeculae of the transplant became necrotic and the lacunae were empty, some of the transplanted osteogenic elements seemed to survive and proliferate in a number of instances. This was manifested by the development of osteoid seams along the trabecular surfaces before the transplant itself had been in contact with and invaded by new bone from the host. Occasionally, new-bone formation was noted within the graft bed surrounding the isolated transplant or within the undifferentiated tissues that had invaded the intertrabecular spaces. It is suggested that this new bone, forming within the undifferentiated cellular bed, in the vicinity of the bone transplants, may represent osteogenesis derived from transplanted osteoblasts that had migrated into the favorable environment of the bed [4]. The possibility of induction, however, could not be excluded. Whether this observed bone formation represents either the migrations of osteoblasts or the induction of bone formation, it suggests that the phenomenon depends on proper timing of the introduction of the graft. When the graft was placed in a vascular cellular bed of appropriate age, capable of this type of response, bone formation took place.

Under the conditions of these experiments a defect, 0.5 centimeter long, and seven days old in the rabbit or ten days old in the dog, apparently contained the type of bed most suitable for the establishment of optimum host-transplant relationships after a bone transplant. In these beds, little or no fibroplasia or osteoclasis occurred. Delaying the transplantation the proper length of time in these experiments appeared to potentiate the host's ability to develop a more satisfactory relationship with autogenous iliac-bone transplants. These findings are perhaps supported by the clinical observation [42] that in a series of forearm fractures treated with bone grafts, non-union occurred in a significant number of patients in whom the operation was performed soon after the fracture, whereas no failures occurred in the patients in whom grafting had been postponed for at least one week after fracture.

SUMMARY

The present experiments represent the first portion of a study of the relationships between the host and bone transplants in rabbits and dogs. Fresh autogenous iliac grafts, as well as autogenous iliac bone with attached one-week-old

callus, were transplanted to fresh defects and to defects previously created at various time intervals in the ulna (delayed bone transplantation).

Delaying transplantation until the hematoma had been largely replaced by a vascular undifferentiated tissue caused the cellular elements arising from the host bone and periosteum to make more rapid contact with the transplant and to invade the transplant more quickly. Introduction of a bone transplant into a fresh or four-day-old bed, on the other hand, resulted in necrosis of all the transplanted elements, since the graft remained dormant in the blood clot and organizing hematoma until later, when contact was made with the invading cellular and osteogenic tissues. When the transplants were placed in older defects that were filled with denser cellular elements, these transplants were often isolated from the invading new bone by the formation of a barrier of connective tissue. They then became encapsulated and were removed by osteoclasis.

Proper timing of the introduction of the graft into a delayed bed appeared to be important for the development of optimum host-transplant relationships. The presence of osteoid seams along the trabecular surfaces of grafts placed in seven-day-old delayed beds in rabbits and ten-day-old delayed beds in dogs before contact of the grafts was made with the bone invading from the host, appeared to represent surviving and proliferating osteogenic elements of the transplant. The formation of new bone in the vicinity of transplanted fragments isolated within the graft bed suggested either osteogenic activity of surviving transplanted endosteal osteoblasts that had migrated into the favorable environment of the delayed bed or an induction phenomenon.

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Comparative Studies on Bone Matrix and Osteoid by Histochemical Techniques*

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Osteoid tissue is defined as unmineralized bone matrix, and, ordinarily, once formed such tissue will mineralize if the immediately adjacent interstitial fluid is appropriately constituted. However, in a number of clinical situations not accompanied by any recognized aberration in the concentrations of calcium and phosphorus or in the pH of plasma, osteoid tissue is readily detectable in suitably prepared histological sections. Examples of such states are the "physiologic" osteoid present in growing infants and children [26], the osteoid occurring at sites of recent bone fractures [40], and that in patients with osteosclerosis [9]. A tentative explanation for the unmineralized osteoid encountered in these circumstances is that the growth rate of osteoid simply exceeds the rate at which ions necessary for bone-crystal formation are transported to it.

That the transport rate of ions is not necessarily the limiting factor in the mineralization of osteoid is suggested by a number of observations. Several investigators, using various histochemical and physical techniques, reported that osteoid may be shown to differ from bone matrix [16,20,31,32]. Furthermore, it has been recently proposed that osteoid, as initially formed, is not mineralizable and becomes so only after biochemical or physicochemical alteration [15]. That osteoid is not a readily mineralizable tissue is supported by several communications [17,35], and also by studies demonstrating that osteoid does not mineralize under conditions which induce extensive mineralization of adjacent hypertrophic cartilage matrix either *in vivo* or *in vitro* [37].

The present experiment was planned in order to study extensively the histochemical characteristics of bone matrix as compared with those of osteoid and cartilage matrix by making observations on bones from animals in which large amounts of osteoid had been induced by several different means. The results obtained confirm and extend those of previous workers that osteoid does indeed differ histochemically from bone matrix in several respects. Moreover, interpretation of the chemical implications of these results permits formulation of a concept as to the nature of the difference between osteoid and bone matrix.

METHODS

Experimental Animals

Bones utilized in this experiment were obtained from each of the following three groups of rats:

1. Wistar strain weanling rats ** made rachitic by feeding a high-calcium-low-phosphorus rachitogenic † diet for twenty-one to thirty-two days prior to sacrifice;

2. Similar rats in which low-calcium rickets was induced by feeding a low-

* This work was initiated during the tenure of an Arthritis and Rheumatism Foundation fellowship in the Metabolic Division, The Johns Hopkins Hospital, and was subsequently supported at the University of Florida by Grant No. NIH-A-1772 from the Institute of Arthritis and Metabolic Disease of the National Institutes of Health.

** Obtained from Research Supply Co., Philadelphia, Pennsylvania.

† U.S.P. Rachitogenic Diet #2, obtained from General Biochemical Co., Chagrin Falls, Missouri.

calcium-high-phosphorus diet [38] for the same period of time as in the preceding group;

3. Weanling rats in which hypervitaminosis D rickets was present as the result of oral administration of vitamin D_2 (400,000 units per kilogram of body weight per day) for fourteen days [29].

The histological appearance of the bones differed in each of these three types of experimental rickets, but in all bones there was abundant osteoid tissue available for study.

Histochemical Techniques

Undecalcified histological sections of the proximal portion of tibiae were prepared, unless otherwise stated, according to a modification of the method of Axelrod [1] by fixation in 4 per cent formalin (rendered neutral or alkaline by an excess of magnesium carbonate) prior to embedding in celloidin and staining with silver nitrate, hematoxylin, and eosin. Such sections were used as controls, with adjacent sections being used for each of the histochemical procedures utilized. Fresh or fixed but unembedded bone was sectioned on the freezing microtome and stained immediately, as subsequently specified. Demineralization of appropriate sections was accomplished by brief immersion in 0.1N hydrochloric acid or 9 per cent trisodium versenate ††. Alizarin staining was performed with 1 per cent sodium alizarin sulphonate [4]. The periodic acid-Schiff reaction used was that described by Hotchkiss [14] and by McManus [24]. Metachromasia of bone was determined with 0.5 per cent aqueous toluidine blue, the sections being examined immediately after brief staining (for two to three minutes) [22]. The affinity of bone tissues for a basic dye was judged by the methylene-blue extinction procedure of Dempsey and Singer [5], as modified by Pearse [27]. Methylation of carboxyl and other acid radicals was determined with formalin-fixed, unembedded bone sectioned on the freezing microtome [8]. These sections were then incubated in methanol containing .05N hydrochloric acid for one-half, one, two, and four hours, respectively, at 58 degrees centigrade prior to staining with toluidine blue. The histochemical detection of protein-bound sulphydryl and disulphide groups was done by the method of Barnett and Seligman [2], using paraffin-embedded sections of undemineralized or demineralized bone fixed with ethyl alcohol (80 per cent). Reactions for protein-bound free amino groups [41] were conducted with undemineralized bone sections fixed in absolute alcohol and embedded in paraffin, and duplicate sections were similarly prepared after demineralization in trisodium versenate. Staining for the presence of iron was done according to Perls' method, as modified by Bunting [3], using celloidin-embedded bones previously fixed either in neutral formalin or in absolute alcohol and counterstained with 1 per cent neutral red. Distribution of (S^{35}) sulphate was determined in rachitic rats after injections of forty microcuries of carrier-free (S^{35}) sulphate as sodium sulphate § nine, six, and three days prior to sacrifice [6] and in other rats that received a single such injection twenty-four hours before sacrifice. Bones from these rats were embedded in celloidin and radioautographs were prepared, using a strip film ‖ technique. Succinic-dehydrogenase activity [25] was estimated in fresh bones which had been quick frozen in a mixture of isopentane, acetone, and dry ice, stored overnight at −20 degrees centigrade, and sectioned in the cryostat at that temperature. Alkaline-phosphatase activity was determined in bones which had been fixed in 4 per cent neutral formalin at

†† Obtained from Bersworth Chemical Co., Framingham, Massachusetts.
§ Obtained from Abbott Laboratories, Oak Ridge, Tennessee.
‖ Obtained from Kodak Limited, London, England.

4 degrees centigrade for eight hours prior to sectioning in the cryostat at −20 degrees centigrade and stained immediately by the method of Manheimer and Seligman [21], using alpha naphthol phosphate.

RESULTS

The results obtained when the various histochemical techniques were applied to rachitic bone were consistent. They indicated that osteoid differs in certain respects from bone matrix, but the cartilage matrix, osteoid, and bone matrix in each of the three types of induced rickets exhibited identical histochemical qualities. Therefore, the results to be recorded are applicable to the cartilage matrix, osteoid, and bone matrix, respectively, of all three types of rickets. For convenience of comparison, certain of these results are listed in Table I.

Hematoxylin, Silver Nitrate, and Alizarin Stains

The mineralized portions of fresh (frozen) or celloidin-embedded undecalcified bone sections were readily stained by hematoxylin, silver nitrate, or alizarin, whereas the osteoid in these sections was unstained by these compounds. Bone decalcified in diluted hydrochloric acid to the extent that it failed to stain with silver nitrate could still be stained faintly by hematoxylin; but decalcification by this procedure was incomplete, as indicated by the persistence of stainability with alizarin, a more sensitive indicator of bone mineral [4]. Silver staining of mineralized matrix was prevented by prior staining with hematoxylin, indicating the possibility of competition for linkage sites by these two compounds. Conversely, staining of mineralized matrix with alizarin did not interfere with subsequent staining by silver nitrate. This latter observation is consistent with the known propensity of silver to react with phosphate groups and alizarin with calcium or other cations.

Toluidine-Blue Staining for Metachromasia

In toluidine-stained undecalcified bone sections which had been previously fixed in neutral formalin and embedded in celloidin the osteoid was orthochromatic, whereas cartilage matrix stained with varying degrees of metachromasy. Bone matrix stained metachromatically, although lightly so, in the poorly mineralized low-calcium and low-phosphorus rachitic bones, but was moderately metachromatic in all three types of bones under study if they were demineralized prior to embedding. In fresh-frozen sections osteoid stained metachromatically to a degree identical to that of demineralized bone matrix, whereas cartilage matrix was intensely metrachromatic in such sections, and prior fixation in neutral formalin did not alter these metachromatic qualities. Brief exposure of fresh or formalin-fixed unembedded sections to methyl or 95 per cent ethyl alcohol prevented metachromatic staining of osteoid, but exposure to xylene, benzene, toluene, chloroform, acetone, or glycine did not alter the metachromasy of this tissue. Celloidin-embedded sections reacted differently from the sections just mentioned in that exposure to xylol now interfered with the metachromatic staining in both bone and cartilage matrix.

Effect of Methylation on Toluidine Staining

Incubation of formalin-fixed sections for one-half hour in the acid methanol solution completely prevented staining of bone matrix and osteoid by toluidine. Similar incubation of cartilage for two hours caused the staining of cartilage matrix to be limited to the area of hypertrophic cells, and the staining of cartilage

cells and osteoblasts to be detectably reduced from that occurring in control sections. There was no staining of any of the components of cartilage—cells or matrix — in those sections incubated for four hours in acid methanol.

Methylene-Blue Extinction

The affinity of celloidin-embedded bone sections for methylene blue was determined over a pH range from 8.2 to 2.6. Osteoid was orthochromatic at all pH values, but below pH 3.8, staining of this tissue was barely detectable. Bone matrix did not stain at pH values less than 4.6, whereas cartilage matrix was brightly stained throughout the pH range tested. Certain tissues are known to stain metachromatically with the basic dye, methylene blue, and this was true of cartilage matrix at pH 4.9 to 2.6 and of bone matrix at pH 7.0 to 4.6, with both of these tissues staining orthochromatically at higher pH values. The results of this procedure indicate, therefore, that osteoid has an affinity for this basic dye at lower pH values than was evident for bone matrix. In addition, metachromatic staining of bone matrix occurred over a different pH range from that required by cartilage matrix for similar staining.

Periodic Acid-Schiff Reaction

Osteoid tissue was stained less intensely than bone matrix by the periodic acid-Schiff reaction. This histochemical reaction required brief incubation of tissues in an acid medium, a procedure which demineralized the bone sections used. However, identical results were obtained with bone slices demineralized in di uted hydrochloric acid prior to embedding them in celloidin or in paraffin. Cartilage matrix has long been known to be periodic acid-Schiff positive and similar results were obtained in the cartilage of rachitic bones under study.

Protein-Bound Sulphydryl and Disulphide Groups

Osteoid was only slightly reactive (pale blue staining) for sulphydryl groups, and mineralized tissue remained unstained. However, in demineralized bone matrix the reaction was quantitatively the same as with osteoid. Both osteoid and demineralized bone matrix exhibited much less reactivity than was present in adjacent striated muscle. The degree and location of the staining reaction for disulphide groups was essentially the same as for the sulphydryl groups and again there was much greater reactivity in adjacent muscle.

Free Amino Groups

The histochemical procedure used to indicate the presence of free amino groups resulted in pale staining of the osteoid but not of the mineralized matrix of the trabeculae in the undemineralized sections. In demineralized sections, however, the bone matrix and osteoid reacted to an identical degree. As with the sulphydryl reaction, these tissues stained much less deeply than did striated muscle. Reactions in cartilage matrix for these and the previously mentioned sulphydryl and disulphide groups were too faint for interpretation.

Distribution of (S^{35}) Sulphate

Radioautographs of bones from animals injected repeatedly with (S^{35}) sulphate indicated the presence of much radioactivity throughout the cartilage matrix, with the greatest concentration in the area of mature and hypertrophic matrix. In the cartilage from rats given a single injection of (S^{35}) sulphate, radioactivity was of a lower order but similarly distributed. As previously described [6], the rapid incorporation of labeled sulphate by cartilage portrays the metabolic

TABLE I

SELECTED HISTOCHEMICAL STUDIES ON BONE

Reaction	Osteoid Tissue	Bone Matrix	Cartilage Matrix
Metachromasia (intensity)	++	++	++++
Metachromasia (stability)	+	+++	++++
Resistance to methylation	+	+	+++
Periodic acid-Schiff reaction	+ → ++	+++	++++
Methylene-blue extinction (pH)	3.8	4.6	2.6*
Sulphydryl and disulphide groups	+	+	?
Free amino groups	+	+	?
S^{35}-sulphate distribution	++	++	++++

* pH 2.6 was the lowest tested. No extinction was noted at this pH.

activity of this tissue. Examination of bone trabeculae from the repeatedly injected rats revealed only moderate radioactivity, with no detectable difference in the concentration of radioactivity in osteoid as compared with that in mineralized matrix. Bones from rats injected one day before sacrifice differed from the foregoing in that radioactivity was scant or absent in the trabecular bone with no suggestion of accumulation of labeled sulphate in the osteoblasts bordering osteoid.

Iron Stain

The Prussian-blue reaction applied to bone for the detection of ferric ions gave unexpected results. In these osteoid-encompassed, partially mineralized trabeculae there developed at the peripheral margin of mineralization either a distinct, wirelike, blue line or a broader band of finely granular, blue-stained material. Similar reactivity occurred in the tissues fixed in both neutral formalin and absolute alcohol. Adjacent osteoid tissue was not stained by this procedure. The Prussian-blue reaction was also evident at the mineralization front of calcified cartilage matrix.

Succinic Dehydrogenase Activity

Succinic dehydrogenase activity appeared to be widely distributed. Activity was present in all cartilage cells, including those in the process of degeneration. It was also evident in the cytoplasm of the osteoblasts and of the cells invading the degenerating cartilage of the epiphyseal plate. There was no detectable reactivity in the osteocytes. The scant cytoplasm of these latter cells possibly prevented the detection of this enzyme by this method.

Alkaline-Phosphatase Activity

Phosphatase activity was not detectable in immature cartilage cells; it was present in the cytoplasm of mature and hypertrophic cartilage cells and to some extent in the adjacent cartilage matrix. Osteoblasts were stained quite distinctly and there was faint diffuse staining of osteoid tissue. Osteocytes incorporated within osteoid contained stained cytoplasmic granules, but no reactivity was detected in osteocytes incorporated within mineralized matrix. In this latter instance, as with succinic dehydrogenase, failure to detect enzyme activity may be related to the distribution and paucity of osteocyte cytoplasm.

DISCUSSION

Metachromatic staining of bone and osteoid tissue was described by a number of workers [10,16,20,21,36]. Although previously reported to be evident only if bone

was first demineralized [20], it is not surprising that the poorly mineralized bone matrix from the low-phosphorus and the low-calcium rachitic rats stained metachromatically. The lability of osteoid metachromasia is significant and warrants comment. It is the present consensus that metachromasia indicates the presence of free electronegative, or anionic, charges of such density that the attached dye molecules develop intermolecular bonding [29]. The proximity of dye molecules to each other is thought to determine the stability of the metachromasia. Thus, highly polymerized substances containing closely spaced, free, anionic charges possess a more stable metachromasia than do substances either less highly polymerized or containing more widely spaced anionic charges. Therefore, the lability of osteoid metachromasia may indicate: (1) a lesser degree of polymerization of its components than exists in bone matrix, (2) a reduced number of anionic radicals, or (3) the presence of a compound, a protein, possibly, that blocks some of the free anionic charges. (A lower concentration of the fully polymerized component in osteoid than in matrix would seem to be a less likely possibility than any of these three.)

Evidence to be discussed subsequently suggests that the first of the deductions just mentioned is the most likely explanation for the lability of osteoid metachromasia. Suitably spaced anionic charges of either carboxyl, phosphate, or sulphate groups, or of any combination of such radicals, probably account for the metachromasia of osteoid and bone matrix. Labeled sulphate, administered in large amounts, has been reported to concentrate in the osteoid of newly formed cortical bone, with rather rapid localization more peripherally in such osteones [18]. It is possible that the time intervals following sulphate injections selected in this experiment were not optimum for detection of labeled sulphate concentration within osteoid. However, the uniform distribution of sulphate in trabecular bone, noted after injection of relatively small amounts of radioactive sulphate, suggests that this radical is not a determinant of the metachromasia of osteoid and bone matrix. Moreover, the rapid loss of metachromasia by both osteoid and bone matrix on incubation of formalin-fixed sections in the acid-methanol mixture indicates that in these tissues this property is dependent on the presence of carboxyl rather than of sulphate or phosphate groups [8]. Contrariwise, the concentration of sulphate in cartilage matrix, presumably present as chondroitin sulphate in acid mucopolysaccharides, is such that it may account for much or all of the metachromasia of this tissue. The relative resistance of cartilage matrix to methylation is also consistent with this thesis. It would be desirable, however, to have more direct information on the distribution of phosphate in cartilage and bone matrix and such studies are now in progress.

The capacity of cartilage matrix to bind methylene blue at pH 2.6 was noted previously [5]. In all probability this capacity is dependent on the presence of sulphate-containing acid mucopolysaccharides in this tissue. It is noteworthy that the affinity of osteoid and of bone matrix for methylene blue was dissimilar since staining extinction occurred at pH 3.8 with osteoid and 4.6 with bone matrix. Lacroix reported similar observations on mineralizing osteones of dog bone [16]. Such results may simply indicate a difference in the nature or density of the sites binding the anionic dye in osteoid and bone matrix. These results also support the concept that there is a difference in the mucoprotein composition of these tissues.

The periodic acid-Schiff reaction depends on the presence of an adequate concentration of 1:2 glycol groupings or amino derivatives of such groups [19,28]. In addition, it has been recently established [19] that the intensity of the periodic acid-Schiff reaction of mucoproteins or glycoproteins is determined by the hexose

or pentose content of these complexes. In the bone sections used for this reaction in the experiments reported here, glycogen and other soluble sugars were lost during washing after fixation. Therefore, in all probability the reactivity demonstrated could be attributed to the presence of carbohydrate containing mucoproteins or glycoproteins. The reduced periodic acid-Schiff staining of osteoid noted in this experiment is in keeping with the report of Pritchard [31] and is indicative of a decreased content of reactive substrate in the ground substance of osteoid, as compared with the ground substance of bone matrix*. One possible explanation of this difference is that the carbohydrate-protein complex in osteoid is less highly polymerized than that in bone matrix. This explanation is most consistent with the previously discussed lability of osteoid metachromasia. It is of interest in this connection that Gersh and Catchpole [12] deduced from their observations that the ground substance of newly formed tissues is less highly polymerized than that of older tissues. Additional support for this interpretation may be gained from the report that osteoid contains more water than does bone matrix [22].

Very weakly positive reactions were obtained by the histochemical procedures for the detection of sulphydryl, disulphide, and free amino groups in osteoid and bone matrix. Such studies have not been reported previously. It is of interest that the reactions obtained were of much less intensity than those observed in striated muscle. The significance of such groups in osteoid and bone matrix is unknown. Bone contains very little cystine [7]. Sognnaes [26], while commenting on the weakly positive reactions for disulphide and sulphydryl groups in pre-enamel matrix and predentin, suggested that such groups may be associated with oxidizing systems in the matrix.

It has been noted that iron is often present at sites of pathological calcification and there has been much discussion of the possible role of this element in the mineralization process [3]. Some investigators [3] have suggested that mineralizable matrix has an affinity for iron just as it does for calcium. The occurrence of iron at the calcification front as reported herein is consistent with this thesis for it is known [11,26] that mineralization of trabecular bone proceeds peripherally. However, the observation that readily mineralizable cartilage matrix from rachitic rats did not react for iron suggests that this cation may be involved in the actual process of mineralization or that it is concentrated locally by matrix immediately prior to the formation of the bone crystal.

Bone matrix and osteoid consist of a structured protein, the collagen fibrils, and an interfibrillar ground substance. The histochemical studies utilized herein were applied to both of these phases; it was not possible to distinguish which phase accounted for the reactions obtained. By electron microscopy the structure of the collagen fibrils in osteoid has appeared to be identical with that of the fibrils in bone matrix [33]. Moreover, these fibrils differ little from those in other connective tissues [34]. The observations recorded in this experiment indicate that osteoid does differ in some respects from bone matrix (Table I). In all probability, this represents a difference in the composition of ground substance in these respective tissues. Moreover, it is to be emphasized that the histochemical properties of osteoid were uniform even though the bones studied were obtained from rats with various types of experimental rickets. McLean and Bloom [23], although noting the contrary viewpoint of others, proposed that osteoid mineralizes promptly as formed, providing adequate nutrition exists. However, more recently acquired data [15,16,20,31,32], in addition to those of this experiment, do not support this pro-

* Heller-Steinberg [13], using freeze-dried embedded sections, reported that osteoid is stained more deeply by the periodic acid-Schiff reagent than is bone matrix. An explanation of such results, which are at variance with those noted in this experiment and also with those reported by Pritchard [31], may be in the different method utilized by her for tissue preparation.

posal but rather that expressed years ago by Pommer [30], when he stated that osteoid differs from bone matrix and must undergo change before it becomes mineralizable.

CONCLUSION

In this study a variety of procedures were utilized to examine the histochemical characteristics of cartilage, bone matrix, and osteoid in experimental low-phosphorus, low-calcium, and hypervitaminosis D rickets. The results obtained indicate that each of such tissues exhibits different histochemical properties and that these properties do not vary with the type of rickets induced. Therefore, the data acquired constitute additional evidence that osteoid differs from bone matrix. Interpretation of the observed reactions permits a deduction as to the nature of this difference.

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Intrathoracic Dislocation of the Humeral Head

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Intrathoracic displacement of the humeral head as a result of dislocation of the humerus is an exceedingly rare condition. In a careful search of the modern literature only one case could be found [2]. Watson-Jones mentions one other article in the foreign literature published in 1865 [1].

The following case is unique in that, unlike the case reported by West, the shaft of the humerus was fractured at the surgical neck, leaving the detached humeral head isolated in an intrathoracic position.

FIG. 1-A

Anteroposterior roentgenogram, made on admission, showing the shadow of the humeral head.

FIG. 1-B

The arrows in the lateral view indicate the left humeral head.

REPORT OF A CASE

A woman, seventy-five years old, was seen at the hospital on March 1, 1958, shortly after a fall in which she had landed on her outstretched left arm. There was clinical evidence of dislocation of the left shoulder, but no demonstrable arterial or nerve damage. Likewise, there was no respiratory distress or evident chest complaint.

Roentgenograms of the affected shoulder (Figs. 1-A and 1-B) revealed the presence of a fracture-dislocation of the left humerus, with rather wide displacement of the humeral head. It was not recognized at the time that the head of the humerus was located entirely within the thorax.

Open surgery was planned for removal of the head of the humerus and reattachment of the rotator cuff to the proximal humeral shaft.

The patient was operated upon on the same evening under endotracheal anesthesia. Because of the findings at surgery, it was indeed fortunate that the patient was intubated.

Through a conventional deltopectoral incision, the joint was approached. By finger exploration under the pectoral muscles, the detached humeral head was sought but could not be found. A defect in the chest wall could be palpated between the second and third ribs anterolaterally. The underlying lung could be felt with the examining finger. Further palpation revealed the humeral head to be lying within the chest, resting on the lung. By extension of the surgical incision medially, the defect in the chest wall was visualized, and the head was found lying within the thorax. With some difficulty, the head was delivered through the defect between the ribs and was removed. There was no evidence of rib fracture. The lung was slightly abraded, with small tears of the visceral pleura in several areas.

A soft-rubber intercostal catheter was placed at the apex of the pleural cavity and was passed out through the anterior chest wall. The rotator cuff was attached to the shaft of the humerus, and the incision was closed. By placing the patient in the Trendelenburg position, the pleural space was aspirated, and the tube placed in an underwater-seal drainage. The shoulder was immobilized with a soft Velpeau dressing.

The patient made an uneventful postoperative recovery, except for a mild phlebothrombosis that was treated with anticoagulants. The tube was removed thirty hours after operation, and an occlusive dressing was applied to the chest for an additional twenty-four hours.

Serial roentgenograms of the chest showed no atelectasis or fluid accumulation, and the patient was discharged one month after admission.

After three to four weeks, physical therapy for the shoulder was started. When last seen, two years after injury, the patient had approximately 50 per cent of the function and no pain. She was satisfied with the functional result.

DISCUSSION

An unusual complication of fracture-dislocation of the shoulder has been presented. The actual lesion was not recognized before operation. In retrospect, it was realized that the original roentgenograms showed rather distinctly that the humeral head occupied an intrathoracic position. Strangely enough, there was no clinical manifestation of the chest disorder, and sufficient time had not elapsed for the appearance of subcutaneous emphysema. Another observation of interest was that with such severe trauma, there was no evidence of vascular or nerve damage.

It is supposed that intrathoracic dislocation occurred first, much as the dislocation occurred in the case reported by West, and then with continued stress on the arm, the shaft of the humerus was levered against the rib and fractured, leaving the head trapped within the thorax.

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Crawford Adams Cup Arthroplasty

A Review of Fifty Cases*

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From the Campbell Foundation and the University of Tennessee College of Medicine, Memphis

In 1953, John Crawford Adams described a new type of cup for arthroplasty of the hip and reported on the early results in twenty-four patients. He stated that cup arthroplasty with the standard Smith-Petersen mold had fallen into disrepute with many surgeons because of the inconsistent results obtained with this device and the long period of rehabilitation required after operation.

In referring to the Judet operation, Adams made a strong plea against too liberal use of endoprostheses, particularly in younger patients, and urged reconsideration of cup arthroplasty. The stem type of endoprosthesis has now largely passed out of use; however, Adams' reasoning in 1953 is still valid for the newer medullary prostheses. The advantages of cup arthroplasty are now generally accepted. A good cup arthroplasty can result in a nearly normal hip, and the function of the hip after this procedure usually improves with time. On the other hand, should a cup arthroplasty prove unsuccessful, enough of the femoral head and neck remains to permit either arthrodesis or insertion of a medullary prosthesis.

Adams contended that most of the poor results after Smith-Petersen mold arthroplasty were owing to mechanical imperfections of the new joint. These included the hanging-up of the rim of the cup on the neck or the acetabulum; eccentric movement of the relatively smaller cup within the larger acetabulum; and upward displacement of the axis of motion of the joint, with resultant shortening of the abductors. This displacement was thought to be due to the amount of bone and cartilage removed and the thinness of the cup.

The cup that Adams described was designed for concentric motion within the acetabulum. It consists of two-thirds of a sphere and is designed to fit snugly over the remnants of the neck and head with one-sixteenth of an inch clearance. It was thought that this clearance would give stability and yet leave room for the formation of fibrocartilage. The wall of the cup is one-quarter of an inch thick to prevent displacement of the axis of motion and shortening of the abductors. Flexion and extension can be seen at the time of operation to take place between the cup and the neck, and to a lesser extent between the cup and the acetabulum; all other movements take place between the cup and the acetabulum. Smyth, in discussing the mechanics of the artificial hip in 1958, described the one-piece cup used by Adams as the only artificial hip free of mechanical objection. We have used cups with the same configuration, but assembled from two pieces—an outer and an inner cup welded together at the edges, with a supporting piece fixed between the two cups at their apices. This is obviously not so strong as a cup made from one piece of metal; after two of the operations in this report the two portions of the cup came apart. We are now using a cup of one-piece construction. Both the two-piece cups which we used in this series and the one-piece cup we are now using are available in three sizes, with the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Miami Beach, Florida, January 9, 1961.

TABLE I

DESCRIPTION OF CLASSIFICATION OF RESULTS

Excellent:	Flexion to 90 degrees, less than 10 degrees of flexion contracture, 30 degrees of abduction, and no pain
Good:	Flexion of 60 to 90 degrees, not over 20 degrees of flexion contracture, from 20 to 30 degrees of abduction, and no pain
Fair:	Flexion of 45 to 60 degrees, not over 30 degrees of flexion contracture, from 10 to 20 degrees of abduction, and minimum pain
Poor:	Flexion to less than 45 degrees, flexion contracture of more than 30 degrees, from 0 to 10 degrees of abduction, and significantly less pain than before operation
Failure:	Hips that required surgical revision * or caused severe pain

* Two revisions with replacement of the Crawford Adams cup were not considered failures: in one, the result was excellent after a broken cup was replaced; in the other, the result was good after the second procedure, for the removal of ectopic bone.

TABLE II

OVER-ALL RESULTS *

Result	No. of Arthroplasties
Excellent	11
Good	15
Fair	8
Poor	11
Failure	5
Total	50

* Range of follow-up was from twelve to seventy-two months; the average, thirty-eight months.

TABLE III

END RESULTS CLASSIFIED IN RELATION TO DISEASE

Disease	Number of Results					
	Excellent	Good	Fair	Poor	Failure	Total
Osteo-arthritis	3	4	4	6	1	18
Arthritis secondary to trauma	7	2	2		1	12
Degenerative arthritis secondary to congenital dislocation or to coxa plana		5	1	1	1	8
Septic arthritis	1	1		1	1	4
Rheumatoid arthritis		3	1	3	1	8
Totals	11	15	8	11	5	50

following outside and inside diameters: (1) *small*, one and seven-eighths inches, and one and one-fourth inches; (2) *medium*, two and one-eighth inches, and one and one-half inches; and (3) *large*, two and three-eighths inches, and one and three-fourths inches. Three different sizes of reamers for the acetabulum and of shapers for the femoral head are also available for use with the corresponding size of cup.

PRESENTATION OF CASES

We first used the Crawford Adams cup in 1954 and since that time have performed sixty arthroplasties twelve months or more before the date of com-

TABLE IV

ANALYSIS OF FIVE FAILURES

Patient	Diagnosis	Analysis
H.T.	Osteo-arthritis	Patient had good motion, but severe pain; arthroplasty had been done with too little available head and neck; at 25 mos. after operation, revision was done with Austin Moore prosthesis; result was fair
K.P.	Rheumatoid arthritis	Poor motion, moderately severe pain, and marked ectopic bone formation; at 48 mos. after operation, patient was not yet willing to have revision
E.S.	Septic arthritis	In retrospect, patient probably had active low-grade septic arthritis at time of arthroplasty; at 3 mos. after operation she had absorption of the head, varus displacement of the cup, and severe pain; revision with Whitman operation brought satisfactory result
L.H.	Osteo-arthritis	Patient had osteo-arthritis; absorption of head, varus displacement of cup, and severe pain 16 mos. after operation; 18 mos. after operation revision done with Thompson prosthesis; result was excellent
G.S.	Arthritis secondary to traumatic dislocation of the hip	Cup broke 42 mos. after operation; moderate pain developed; head beneath cup showed avascular necrosis; revision done with Thompson prosthesis; result was good

pletion of this study (November 16, 1960). We have been able to follow fifty (83 per cent) of these sixty arthroplasties in forty-three patients, seven with bilateral arthroplasties. The length of follow-up ranged from twelve to seventy-two months, an average of thirty-eight months.

Nineteen arthroplasties were performed at the Campbell Clinic by members of the permanent staff; thirty-one were performed at the Hospital for Crippled Adults by resident fellows of the Campbell Clinic under the supervision of a member of the permanent staff. A modified Gibson posterolateral approach with osteotomy of the greater trochanter was used in forty-six operations. The Smith-Petersen approach was used in four operations on patients with rheumatoid arthritis and ankylosis in marked flexion.

The primary indication for operation was severe pain in forty-five cases, and loss of motion in five patients with fibrous or bony ankylosis.

The age of the patients at the time of operation ranged from seventeen to seventy-seven years; the average age was forty-nine years.

The diseases of the hip joints involved were: osteo-arthritis in eighteen hips, arthritis secondary to trauma in twelve, arthritis secondary to congenital subluxation or coxa plana in eight, old septic arthritis in four, and rheumatoid arthritis in eight. In the classification *arthritis secondary to trauma* are included hips with avascular necrosis or arthritic changes secondary to fracture of the neck of the femur or traumatic dislocation of the hip.

RESULTS

So many variables influence the results of hip arthroplasty that classification of the results is difficult. We have based our classification on the range of flexion, the range of abduction, the degree of flexion contracture, and the amount of pain (Table I). The over-all results in this series are shown in Table II; the results classified according to disease, in Table III. Since the primary indication for this operation is pain, relief of pain is essential to a satisfactory result. All patients in this series had significant relief of pain, with the exception of the five patients with results classified as *failures*, and of these five, one does not have enough pain to be willing to submit to a revision. Most of the patients

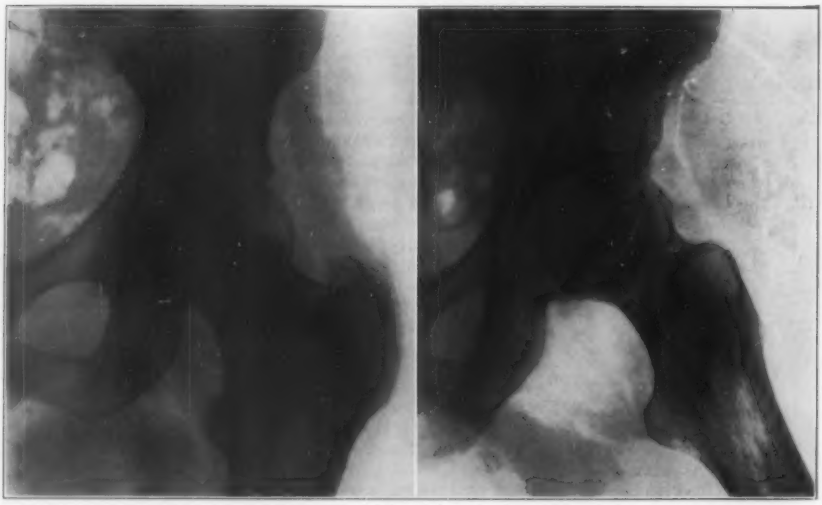

FIG. 1-A

Roentgenograms of N. C., a woman, fifty-six years old, showing avascular necrosis of the femoral head secondary to an old, healed fracture of the femoral neck.

(forty-five) have little or no pain. Two revisions, one to replace a broken Crawford Adams cup, the other to remove ectopic bone, were not considered failures. In one, the result was excellent after the broken cup was replaced; in the other the result was good after removal of the ectopic bone and replacement of the same cup. After forty-five (90 per cent) of the fifty arthroplasties, the patients are happy that they had the operation.

The results of eleven arthroplasties were classified *excellent*. These hips have nearly normal function; the patients walk with very little limp and have no pain. Two illustrative cases follow.

N. C., a woman, fifty-six years old, fractured the neck of the left femur three years prior to being seen at the Campbell Clinic. Multiple-pin fixation had been employed and the fracture had united, but pain, which developed approximately eighteen months after fracture, gradually became more severe. Roentgenograms (Fig. 1-A) showed avascular necrosis of the femoral head with collapse of the weight-bearing portion. On September 4, 1956, arthroplasty with a Crawford Adams cup was performed. Roentgenograms made at one month and at thirty-six months after operation (Fig. 1-B) showed no change in the position of the cup. Motion in the left hip was normal, as compared with the opposite side. The patient has no pain, walks without a limp, and has resumed her work as a saleswoman.

B. J., a man, sixty-one years old, was seen at the Hospital for Crippled Adults because of severe pain in his left hip. Eight years earlier, a falling tree had caused a subtrochanteric fracture of the left femur; the fracture had united in marked varus position. Roentgenograms revealed coxa vara with advanced arthritic changes in the left hip. Arthroplasty with a Crawford Adams cup was performed in September 1955 (Fig. 2-A). The plan was to perform valgus osteotomy a few months later, but arthroplasty completely relieved the patient's pain and he refused the osteotomy. Despite the varus deformity, roentgenograms four years later (Fig. 2-B) showed that the position of the cup had not changed significantly. Now, five years after arthroplasty, the patient continues to be free of pain and works as a commercial fisherman. With a three-inch build-up on his shoe, he walks with almost no limp. Motion in the hip is from 180 degrees of extension to 70 degrees of flexion; other movements of the hip are normal except for abduction, which is limited by the varus deformity to 20 degrees.

The arthroplasties with *good*, *fair*, and *poor* results are so classified largely because of the lack of motion of the hip; many of these hips, however, are very serviceable.

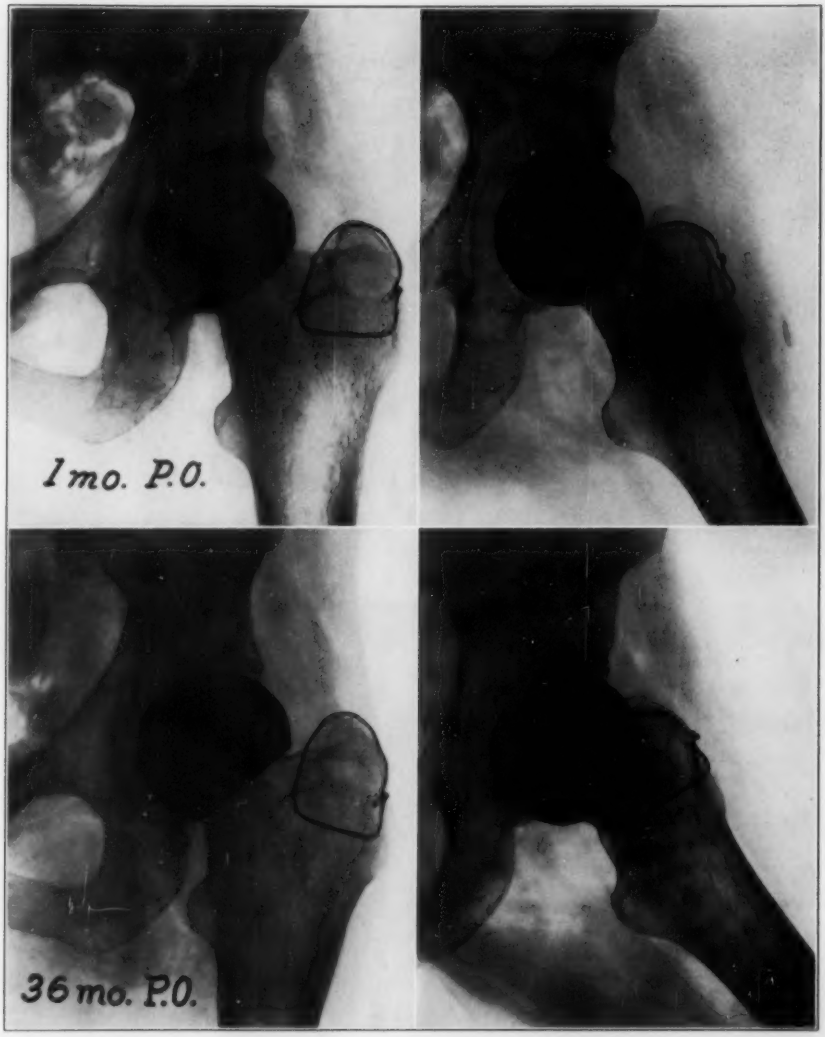

FIG. 1-B

Roentgenograms made one month (top) and thirty-six months (bottom) after arthroplasty.

Although this series is too small to permit significant correlations of the results with the types of disease, it is interesting that most of the excellent results are in patients with arthritis secondary to trauma. The more favorable results in this condition may be related to the relatively short duration of the hip disability and the resultant more normal musculature and to the more normal acetabulum usually seen in this condition. Rehabilitation tended to be easier and to be accomplished earlier in this group; a stable end result had usually been reached twelve months after operation. In contrast to the results in this group, the results in the patients with congenital dislocation and coxa plana were usually only fair or poor at twelve months. However, the function of these hips has continued to improve for as long as thirty months, at which time most of the

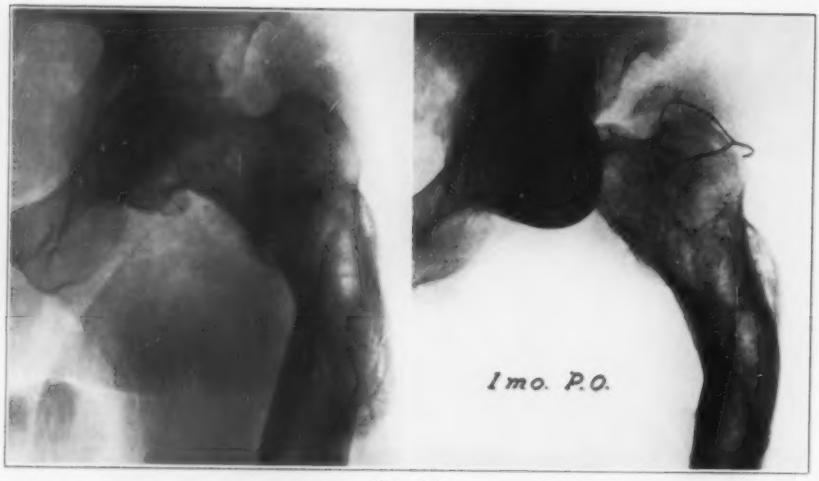

FIG. 2-A

At the left, the roentgenogram of the left hip of B. J., a man, sixty-one years old, shows severe degenerative arthritis secondary to an old subtrochanteric fracture which has united in marked varus position. The roentgenogram at the right was made one month after arthroplasty.

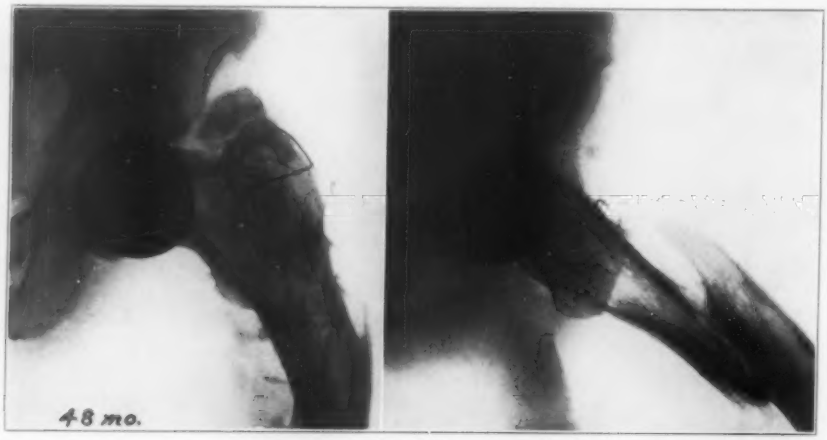

FIG. 2-B

Forty-eight months after arthroplasty.

results could be classified as *good*. The reason for the slow rehabilitation may be the long-standing changes in the muscles and the acetabular distortion which necessitated extensive reconstruction.

The group with rheumatoid arthritis contains some of our happiest patients. Despite the relatively poor ratings given to these hips in our formal classification (Table III), the true evaluation of each patient's benefit from the procedure in this disease can only be made by comparing the condition of the hip after operation with that before treatment. The function in such a hip cannot be compared fairly with that of a normal hip. Although the motion obtained after arthroplasty for rheumatoid arthritis is often not great (and some of our results are therefore classified as only *fair* or *poor*), what motion is gained is of tremendous

FIG. 3-A

Roentgenogram of J. G., a seventeen-year-old girl, showing ankylosis of both hips, secondary to Still's disease.

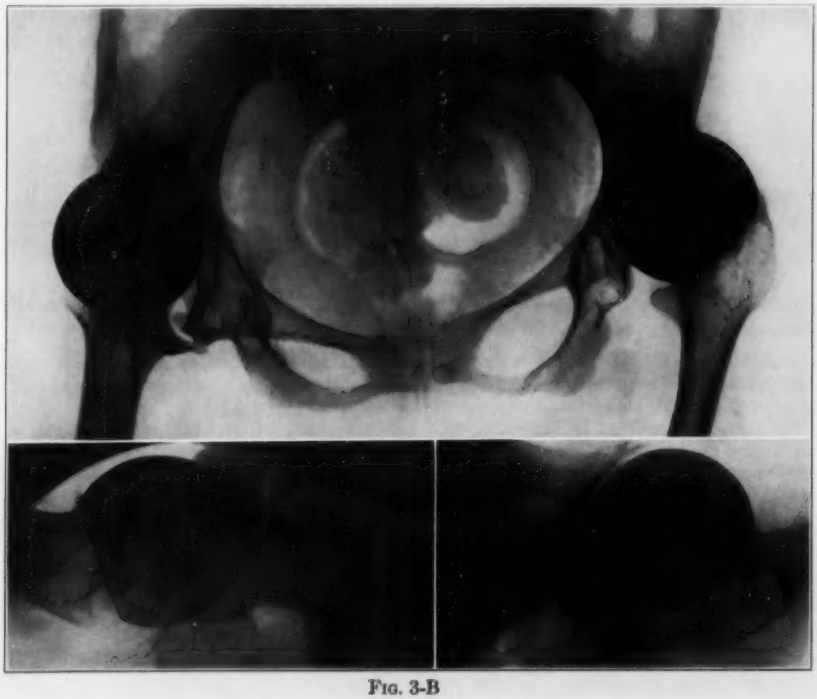

FIG. 3-B

Four years after bilateral arthroplasty.

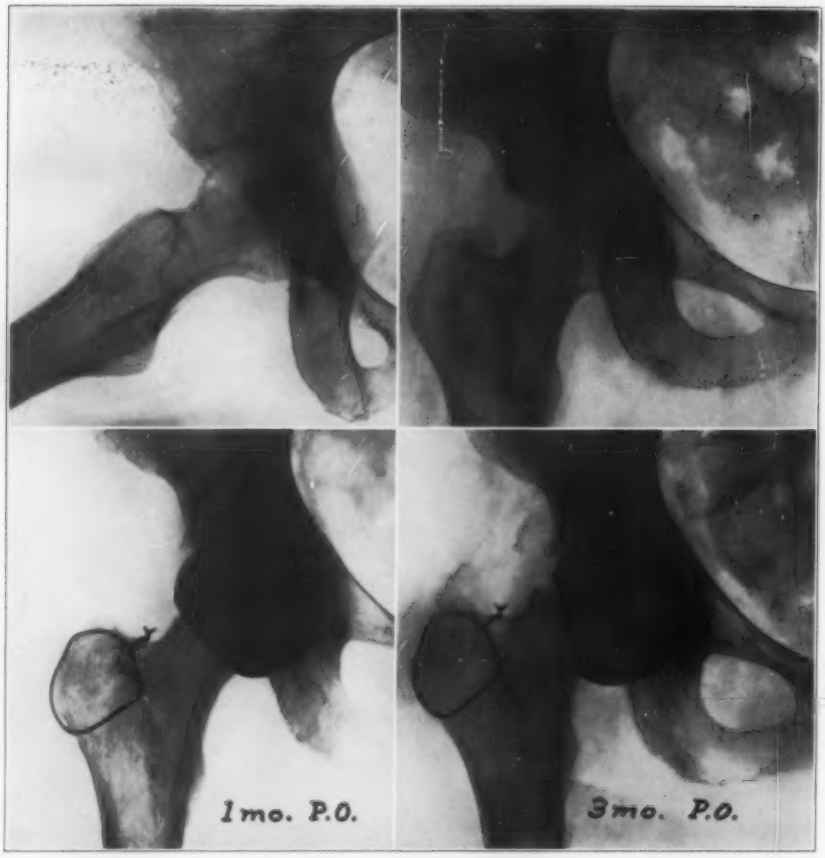

FIG. 4

The roentgenograms at the top show the right hip of E. S., a woman, fifty-eight years old, in whom the initial diagnosis was osteo-arthritis. The lower roentgenograms were made one month and three months after arthroplasty: the latter shows the cup in marked varus position. The patient probably had active, low-grade, septic arthritis at the time of operation.

help; for example, two patients who had been in wheel chairs for years became ambulatory. One of these we present here.

J. G. had Still's disease when she was six years old. The disease became quiescent by the time she was seventeen, but she was left with severe deformities; both hips were ankylosed at 120 degrees (Fig. 3-A), both knees had severe flexion contractures, and her feet and ankles were in marked equinus position. In September 1955, an arthroplasty with a Crawford Adams cup was performed on the left hip, and one month later on the right hip. During her convalescence from these operations, the deformities of her knees and feet were corrected by surgical procedures. She could then walk on crutches. Four years later, she had motion from 180 to 90 degrees in the left hip and from 180 to 100 degrees in the right hip (Fig. 3-B). She was able to attend college and has recently graduated.

Of the five patients classified *failures* (Table IV), two were so classified because of pain (H. T. and K. P.). In one of these, H. T., we now believe that there was too little neck and head originally available for a successful arthroplasty by the technique employed. No significant change in the position of the cup was seen in roentgenograms made after operation, but at reoperation the cup was found to be abutting against the greater trochanter. An Austin Moore

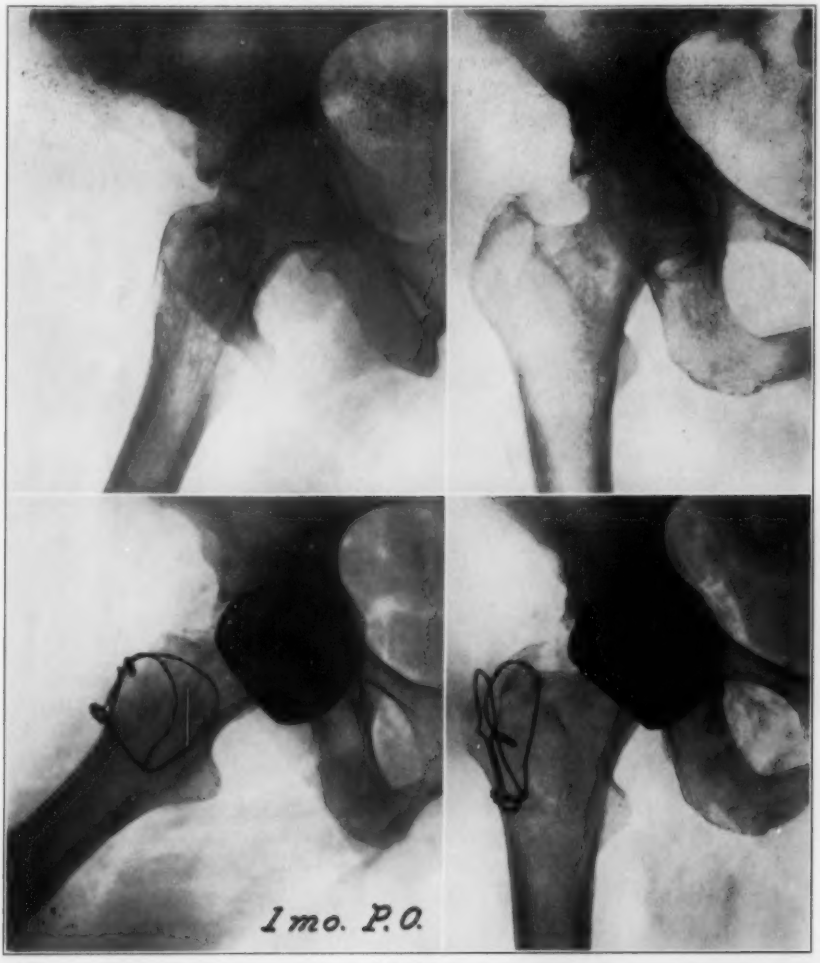

FIG. 5-A

The roentgenograms at the top show osteo-arthritis of the right hip in L. H., a seventy-year-old woman; those at the bottom were made one month after arthroplasty.

prosthesis was inserted at this operation, giving a fair result. The other patient, K. P., complained of moderately severe pain, but forty-eight months after operation he did not consider the pain severe enough to warrant revision. He has marked ectopic bone formation about the trochanter and superior rim of the acetabulum.

At the beginning of this study, it was anticipated that avascular necrosis of the head beneath the cup might be a problem with this device because of the relatively tight fit. Significant resorption of the head and neck did occur in three patients. One of these, E. S. (Fig. 4), probably had a low-grade infection in the hip at the time of arthroplasty. Pain developed and there was varus displacement of the cup three months after operation. At reoperation, the head was found to have been resorbed, with granulation tissue beneath the cup. Culture was positive for *Staphylococcus aureus*. A Whitman reconstruction was performed with a satisfactory result. In the other two patients (Cases L. H. and

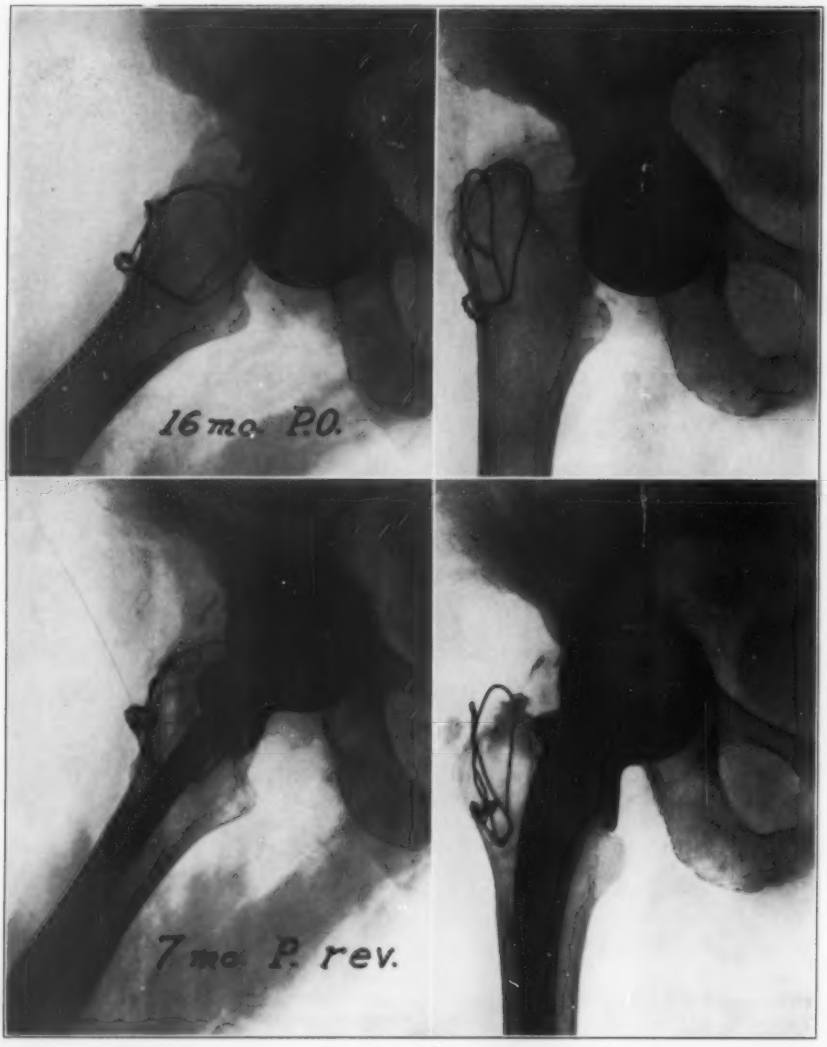

FIG. 5-B

The roentgenograms at the top, made sixteen months after arthroplasty, show the cup in varus position. At reoperation, the femoral head and neck were found to be resorbed. The roentgenograms at the bottom were made seven months after revision with a Thompson prosthesis.

G. S.) resorption was probably caused by avascular necrosis. In L. H., who had osteo-arthritis of the hip (Fig. 5-A), the head was resorbed, and varus displacement of the cup occurred sixteen months after operation (Fig. 5-B). Revision was done with a Thompson prosthesis, giving an excellent result. The last failure was G. S. (Fig. 6-A), who had an excellent result until forty months after operation; he then felt a snap in his hip and pain. Roentgenograms showed that the two portions of the cup had come apart (Fig. 6-B). At operation, the head and neck were found to be partially resorbed, and a Thompson prosthesis was inserted, giving a good result. Figure 6-C shows the broken cup and, for comparison, an intact cup.

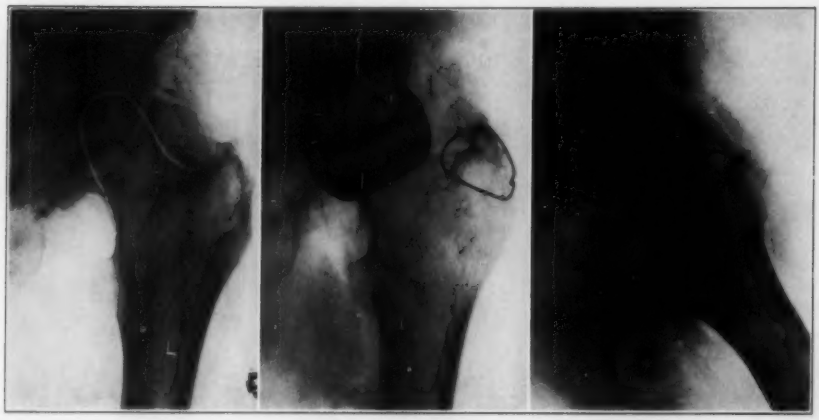

FIG. 6-A

The roentgenogram at the left shows severe degenerative arthritis secondary to an old dislocation in the left hip of G. S., a man, fifty-four years old. The bone to be removed at arthroplasty is outlined. The roentgenograms at the right show the cup in good position nine and a half months after operation.

FIG. 6-B

Roentgenograms made forty months after arthroplasty show that the two portions of the cup have come apart.

In one other patient a similar mechanical failure of the cup occurred, but at operation the head was found to be in excellent condition and covered with good fibrocartilage. The broken cup was replaced with a new Crawford Adams cup, and the patient continues to have an excellent result four years later.

In the only other patient in whom a second operation was necessary, marked ectopic bone formation developed about the hip and he had moderately severe pain three years after arthroplasty. A revision was done by excising the ectopic bone and replacing the same cup. He has a good result eleven months after this revision.

SUMMARY

Fifty arthroplasties of the hip in forty-three patients with use of the Crawford Adams cup are reported.

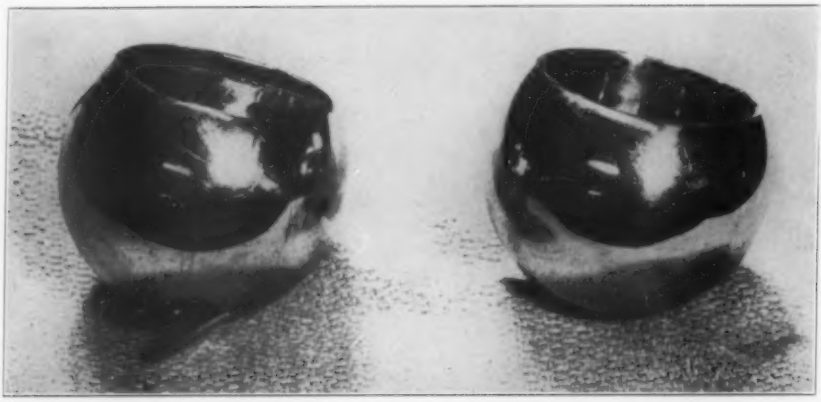

FIG. 6-C

The broken cup removed from the patient's hip is photographed for comparison with an intact cup.

In general, the results have been satisfactory. Severe pain, the primary indication for operation, was relieved in forty-five of the fifty hips. The majority of excellent results occurred in hips with arthritis secondary to trauma.

Necrosis of the head beneath the cup, recognized as a possibility at the beginning of this series, materialized in three patients. One of these represents the only case of infection in the series, and this was probably present at the time of arthroplasty.

Two cups broke because of mechanical faults. The method of manufacture has been changed so that the cup is now constructed of one piece of metal.

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DISCUSSION

DR. WILLIAM H. BICKEL, ROCHESTER, MINNESOTA: Mechanical perfection is the goal of all arthroplasties of the hip. Sometimes, however, the physiological response of the body to mechanical strains is not calculated correctly, and functionally sound tissue may be unnecessarily sacrificed. The current swing to replacement arthroplasties is not entirely justified by the results thus far. Complications from this procedure continue to mount. There is some question in my mind whether the swing is not due to the ease of this operative procedure.

It is my feeling that among properly selected cases the end results from cup arthroplasties of the hip still compare favorably with those obtained by endoprostheses. Where the acetabulum is not intrapelvic, where the head and neck are not in too much varus position, and where there is sufficient stock to shape a good femoral head, I believe a cup arthroplasty is still the procedure of choice. I realize there are other considerations which are too numerous to go into at this time.

Dr. Waring and Dr. Anderson agree with this basic premise. They are seeking the ideal cup and report a series of fifty arthroplasties done with the Crawford Adams cup. Their results are commendable. My personal experience with this cup hardly justifies my being here to discuss its use: but I have tried it in a small group of patients, only to abandon it and return to the standard Smith-Petersen cup, which I think is better in routine cases. By routine I mean the case in which it is not necessary to trim down a much enlarged deformed head and fashion a large cavity for an acetabulum, leaving great incongruity between the head and the acetabulum. Here a thick cup, such as the Crawford Adams or the modified Smith-Petersen cup, is needed to fill space.[1]

Trimming down the head and neck of the femur to fit into a standard-size Crawford Adams

(Continued on page 449)

Concomitant Unilateral Hip and Femoral-Shaft Fractures—A Too Frequently Unrecognized Syndrome

Report of Five Cases

BY CAPTAIN EDWARD E. KIMBROUGH, *Medical Corps, United States Army*

From Brooke General Hospital, Fort Sam Houston, Texas

Although present-day high-speed transportation produces many patients with multiple major fractures, the high efficacy of modern resuscitative methods enables many of these patients to survive. This paper is presented to demonstrate that concomitant unilateral hip and femoral-shaft fractures are frequently produced by this type of trauma and that they are often undiagnosed until too late for optimum treatment.

The five patients in this report were all admitted within a period of nine months (March through November 1958) to Brooke General Hospital. The hip fracture was initially undiagnosed in four of the five patients, thereby prejudicing the end result in at least two of the patients. All of the undiagnosed fractures had been handled by competent physicians, in some instances by experienced orthopaedists, for periods of from two days to one and one-half years without recognition of the hip fracture.

CASE REPORTS

Case 1. A veteran, fifty-three years old, had sustained multiple fractures in an automobile accident in September 1956, one and one-half years prior to admission to Brooke General Hospital on March 12, 1958. A fracture of the left femoral shaft was treated with an intramedullary rod the day after injury. Walking with crutches was started six weeks later. The fractured femur healed nicely, but the patient continued to complain of hip pain so bitterly that, one and one-half months prior to admission to the Brooke Hospital (sixteen months after the accident), the intramedullary rod was removed. Because persistent pain precluded walking, the patient sought examination at this hospital, where he was found to have an extremely painful left hip and one inch of shortening of the left lower extremity. Roentgenograms revealed an old fracture, with non-union of the left femoral neck (Fig. 1). The patient's physician was chagrined to find, on reviewing his roentgenograms, that the hip fracture was visible on the original roentgenograms but it had been missed.

At operation at Brooke General Hospital the presence of aseptic necrosis of the femoral head was confirmed when the head was found to be sclerotic with many soft and cystic spots, and there was almost complete degeneration of the articular cartilage. An Austin Moore replacement arthroplasty was performed. Walking with crutches was started six weeks after operation. Considerable weakness of the muscles about the left hip delayed full weight-bearing without crutches for almost six months.

At the time of writing, over two and one-half years after insertion of the prosthesis, the patient was unemployed because of pain in the left hip. He was able to walk three city blocks with a cane and to stand for two to three hours, but he then had to sit down and rest to relieve the hip pain. His lower extremities were of equal length, there was no appreciable atrophy of the left thigh, and he had virtually full range of motion of the left hip. It is believed that the severity of the symptoms was somewhat exaggerated by the patient's enjoyment of his unemployment compensation.

Case 2. A white male soldier, thirty-five years old, was in an automobile accident in Germany on February 19, 1958, and sustained a laceration of the face and scalp, a penetrating chest wound, open fractures of the left humerus and femur, and a severe cerebral concussion. On admission to the first medical installation he was *in extremis*. After resuscitative measures and débridement of the

FIG. 1

FIG. 2

Fig. 1: Case 1. Old fracture with painful non-union of the femoral neck discovered one and one-half years after an injury in which fracture of shaft of same femur was sustained.

Fig. 2: Case 2. Roentgenogram made in the operating room during intramedullary nailing of the femur over three and one-half months after injury. This is the roentgenogram on which the hip fracture was first recognized.

open fractures, the fracture of the femur was immobilized in a spica cast. On May 12, 1958, he was transferred to a larger overseas general hospital where he was resurveyed and where the spica cast was changed. He was then evacuated to the United States.

When the patient arrived at Brooke General Hospital on May 23, 1958, he had satisfactory union of the fracture of the left humerus, non-union and bayonet apposition of the fracture of the left femur, and numerous facial scars. Also found were left spastic hemiplegia and a paralysis of the lateral rectus muscle of the left eye; these were thought to be residual signs of the brain injury.

On June 2, 1958, open reduction of the femoral fracture was performed, using a Küntscher rod. At time of surgery, it was noted that the guide wire and trochanteric reamer met unusually little resistance in the trochanteric region. This finding prompted roentgenographic examination of the left hip (Fig. 2), revealing a femoral-neck fracture which had been unrecognized previously, despite evaluation by three separate orthopaedic staffs. The roentgenograms indicated that the neck fracture was healing, although with some varus deformity. It was decided to accept this situation.

Within three more months, the fractures had healed, and the hemiparesis had improved sufficiently to allow walking with crutches. The patient was at this time transferred to the Plastic and Eye Services for further treatment. He was last seen by the Orthopaedic Service ten months after surgery and thirteen months after the accident at the completion of treatment on the Eye and Plastic Services. At this time, when he was returned to limited military duty, he had a perceptible limp, but this appeared to be due principally to the hemiparesis.

Follow-up examination could not be obtained, but it was learned that at the time of writing, two years and ten months after injury, the patient is on a full-duty status with the Transportation Corps of the United States Army.

CASE 3. A white male veteran, thirty-seven years old, was in an automobile accident on April 12, 1958. He was treated in a civilian hospital with Buck's traction applied to the left lower extremity until his transfer to Brooke General Hospital on April 28, 1958. Examination on admission revealed fracture of the neck of the left femur (Fig. 3-A), supracondylar T fracture of the left femur (Fig. 3-B), fracture of the distal portion of the right radius, perilunar dislocation of the right wrist, and fracture of the right clavicle. Severe anemia and dehydration were corrected during the next

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. Anteroposterior view of the hip fracture, two weeks after injury, at the time of admission to Brooke General Hospital.
Fig. 3-B: Roentgenogram of the supracondylar fracture, made at admission.

FIG. 4-A

FIG. 4-B

Figs. 4-A and 4-B: Case 4. Roentgenograms made on admission to Brooke General Hospital, showing neck and shaft fracture of the right femur. The hip fracture had been unrecognized at the time of original treatment.

week. The left lower extremity was placed in balanced suspension with skeletal traction by means of a Kirschner wire through the tibial tubercle. The hip was flexed to 90 degrees with 15 degrees of internal rotation; the knee was flexed to 90 degrees, resulting in what was judged to be acceptable reduction of both fractures.

With maintenance of this position, the supracondylar fracture healed satisfactorily, but the fracture of the femoral neck failed to unite, and, on September 22, 1958, open reduction, internal fixation, and bone-grafting were performed, combined with abduction osteotomy. Both the fracture and the osteotomy healed well. By February 1959 the patient was walking without crutches or cane, but motion of the knee was limited to 60 degrees of flexion from full extension. The patient has been lost to further follow-up.

CASE 4. A Negro male soldier, forty-four years old, received multiple injuries in an automobile accident on May 4, 1958. He was given initial care at an Air Force installation. The diagnoses of fracture of the right mandible, fracture of the mid-shaft of the right femur, and multiple contusions of the body were established; the patient was transferred to Brooke General Hospital on May 5, 1958.

At Brooke General Hospital, the transfer diagnoses were confirmed, and a fracture of the right femoral neck was found in addition (Figs. 4-A and 4-B). Although the region of the femoral neck was visualized in previous roentgenographic examinations, the fracture was very difficult to see.

On the day of admission to Brooke General Hospital, oral surgery was performed, and the patient was then placed in balanced suspension with skeletal traction on the tibial tubercle. After further stabilization of the patient's general condition, a Smith-Petersen nail was inserted in the right femoral neck. Fortunately, the neck fracture, although not impacted, remained in good position so no reduction was necessary. At operation the patient was merely placed on a standard fracture table, and the Smith-Petersen nail was inserted without manipulation of the cervical fracture. Traction on the tibial tubercle was continued throughout the procedure.

FIG. 5

Case 5. Roentgenogram made at admission, showing intertrochanteric fracture and shaft fracture of the right femur.

After operation, balanced suspension and traction were continued for the treatment of the shaft fracture. After three months, the patient was allowed out of bed in a wheel chair. After six months, walking in an ischial weight-bearing brace was started, and the brace was used until union of the shaft fracture had occurred. Ten months after injury, the patient was walking well without a limp. The lower extremities were of equal length. The patient was discharged to full military duty.

At the time of writing, two and one-half years after the injury, the patient was performing full military duty in Alaska without complaint or difficulty. Roentgenograms made on October 11, 1960, revealed firm union of both fractures in normal position.

CASE 5. A sixty-year-old Negro male veteran was admitted directly to Brooke General Hospital after an automobile accident on November 29, 1958. He was found to have a severely comminuted fracture of the shaft of the right femur and an intertrochanteric fracture of the right hip (Fig. 5). Intra-abdominal injuries were also suspected but ruled out by a negative abdominal exploration.

Orthopaedic management consisted in balanced suspension and traction for five months by means of a Steinmann pin in the distal end of the femur. The patient then progressed to a wheel

chair and to crutches. By July 1959, complete union of both fractures was proved by roentgenogram, and the patient was walking without support; he was discharged from the clinic.

In September 1960, one year and ten months after injury, questioning revealed that the patient had been fully employed as a hotel maintenance man since discharge from the hospital. His activity was unlimited, but he complained of moderate stiffness and aching in the right hip early in the morning. Physical examination was normal except for loss of 15 degrees of external rotation of the right hip. Roentgenograms revealed firm union of both fractures in good position.

DISCUSSION

In none of the four patients transferred to our hospital was the hip fracture diagnosed prior to transfer, and, in one of them, we failed to recognize the hip fracture until the bone in the trochanteric region was noted to be very soft while it was being reamed in preparation for the insertion of the Küntscher nail. The only patient in whom the hip fracture was detected on the day of injury was Case 5 in this series; this patient was admitted directly to our hospital, after we had become alert to the possibility of concomitant unilateral hip and femoral-shaft fractures.

To my knowledge there is only one other previous report [2] of concomitant unilateral hip and femoral-shaft fracture. In this, Delaney and Street reviewed the English literature and reported an experience similar to ours. The hip fracture was not immediately discovered in two of the four cases reported by these authors.

That this is not an extremely rare syndrome is suggested by the fact that five such combined fractures were seen on one moderately busy fracture service in a period of only nine months. However, the only cases reported in the literature are the four cases of Delaney and Street with the addition of four cases personally reported to them by Kreuz, then Chief of Orthopaedics at Oakland Naval Hospital. Of these latter four cases of concomitant unilateral hip and femoral-shaft fracture, only one fracture of the femoral neck was not discovered until after the shaft fracture had been treated with a femoral nail.

Dislocation of the hip combined with fracture of the femoral shaft on the same side is apparently equally as difficult to diagnose as concomitant unilateral hip and femoral-shaft fracture. Dehne and Immermann, after an exhaustive search, found nineteen cases reported and seven mentioned in the literature, added seven cases of their own, and were informed of nine more cases, making a total of forty-two cases of dislocation of the hip combined with fracture of the femur on the same side. In only fifteen of these forty-two cases was the dislocation originally definitely recognized (in ten of these cases, the time of recognition was not stated).

In three of our four patients in whom the hip fracture was overlooked, the hip fracture was discernible on the transfer roentgenograms in retrospect. Therefore, inadequate roentgenographic examination cannot be blamed for the failure to recognize these injuries. It would appear that attention is drawn to the more dramatic shaft fracture, and the possibility of further injury to the same femur is not considered. That this can be a grievous oversight has been demonstrated.

Double fractures of the femur after automobile accidents should be suspected. Earlier diagnosis is the first step toward more satisfactory management of this difficult but not uncommon lesion. Just as consideration is the first step toward recognition, recognition is the first step toward optimum treatment. If a complete diagnosis is made at the outset, the best course toward maximum rehabilitation can be soundly plotted.

In this series only two of the five patients were really satisfactorily rehabilitated. In both instances, the combined lesion was recognized early. In one (Case 4)

a non-displaced femoral-neck fracture was nailed, and the shaft fracture was treated by traction. In the other favorable case (Case 5), an intertrochanteric fracture and a shaft fracture were both treated by traction, and both healed well.

In the three cases with a less than satisfactory outcome, the hip fracture was not recognized until one and one-half years (Case 1), three months (Case 2), and two weeks (Case 3) after injury. All were femoral-neck fractures and all were denied early internal fixation, the generally accepted optimum treatment. The femoral-shaft fractures united satisfactorily; the undesirable result in all these cases was attributable to the neck fracture.

In the only other reported series of similar injuries, Delaney and Street used intramedullary fixation of the shaft fracture, followed by fixation of the hip fracture with three Knowles pins. In all four cases, results were satisfactory.

Watson-Jones and Wiltberger, Mitchell, and Hedrick reported on femoral-shaft fractures combined with ipsilateral hip dislocation as a rare manifestation of severe trauma. Both suggested immediate intramedullary fixation of the shaft fracture, followed by closed reduction of the hip, as the most feasible management of this complicated injury.

The experience gained from this series and the experience of Delaney and Street suggest several avenues of approach to concomitant unilateral hip and femoral-shaft fractures. If the hip fracture is amenable to traction treatment (as is an intertrochanteric fracture), both fractures can be treated with traction with the expectation of good results, as in Case 5. If the hip fracture is not displaced, internal fixation of the hip followed by treatment in traction would be satisfactory, as demonstrated in one case (Case 4).

If the shaft fracture is suitable for treatment by intramedullary fixation, this can be accomplished, and then manipulation and reduction of the hip fracture performed with fixation by three Knowles or similar pins. Delaney and Street have admirably demonstrated the value of this method in their four cases.

There is no experience to indicate the best treatment for a fracture of the femoral shaft that is not suitable for internal fixation and associated with a displaced hip fracture. A possible solution would be direct open reduction of the hip fracture, using a bone-holding forceps to manipulate the proximal shaft fragment and fixing the fractured neck fragments with an appropriate device. The shaft fracture then could be treated by traction, probably without endangering healing of the hip fracture.

That the hip fracture cannot be ignored or treated by less than the best possible treatment has been shown by our early cases, in which some compromise was attempted in deference to the shaft fracture or in which the hip fracture was not recognized early enough for optimum treatment.

SUMMARY

Five cases of concomitant unilateral fractures of the hip and the femoral shaft are reported. In four of these and in two of the other four cases reported in the literature, the hip fractures were not recognized initially, to the detriment of the patient in some instances. Each fracture must receive optimum treatment. Suggestions are made as to how this can be accomplished.

Concomitant unilateral hip and femoral-shaft fracture is a syndrome too frequently unrecognized. Hip fracture should be considered and excluded by clinical and, if necessary, roentgenographic examination in all femoral-shaft fractures. If diagnosed early and treated skillfully, a satisfactory outcome can be expected.

Note: The author is deeply indebted to Colonel Harold S. McBurney, former Chief of the

Orthopaedic Service, Brooke General Hospital, Fort Sam Houston, Texas, for guidance and stimulation and to Captain John Smith for assistance in follow-up of patients.

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DISCUSSION

CRAWFORD ADAMS CUP ARTHROPLASTY

(*Continued from page 442*)

cup with the clearance of one-sixteenth of an inch makes me feel that the patient is being adapted to the operation. The situation varies from case to case; in some instances I believe usable bone is sacrificed, circulation is diminished, and the cup contains mostly cancellous bone, which is more likely to disintegrate. Some of the authors' illustrations show there has been absorption under the cup with a shortening of the femoral neck between the one-month postoperative view and the thirty-six-month postoperative view. The looser fit of the old cup allows circulation-bearing fibrous tissue to grow beneath the cup, and I believe it lends circulation to the newly fashioned head.

The problem of migration of the old type of cup within the acetabulum is due partly, I think, to faulty selection of cases for cups and an inadequate surgical procedure. The cup should sit on the head in a valgus position and stay freely movable on the head and neck in this position.

The acetabulum should be remodeled with a dome superiorly to accept the cup in a valgus position, and the cup should be tested under direct vision to ensure that it fits the acetabulum.

The skirt of the cup should be long enough so that motion does not bring the rim into the acetabulum, or the margins of the acetabulum should be trimmed down so this will not occur.

The shortness of the abductors after completion of a standard Smith-Petersen cup arthroplasty is easily taken care of by transplanting the severed trochanter down or the detached abductors distally on the trochanter, which is almost routine in our clinic.

The paper of Dr. Waring and Dr. Anderson is definitely a contribution to our specialty; and I, too, feel that cup arthroplasty is not an operation of the past.

Recurrent Locking of the Index Finger Due to Internal Derangement of the Metacarpophalangeal Joint

BY JULIAN M. BRUNER, M.D., DES MOINES, IOWA

Locking of a finger in flexion is a fairly common condition, usually caused by tightness of the fibrous sheath (pulley) around the flexor tendon, which may contain a localized fusiform or beadlike enlargement. In the finger, this has been called trigger-finger, and, in the thumb, snapping thumb; both conditions are considered similar in etiology and pathology to de Quervain's syndrome at the radial styloid.

Locking of a single finger joint due to external joint derangement is rare, and locking due to internal joint derangement, as exemplified by the intra-articular blocking seen so frequently in the knee joint, is even less common. The following case is presented because the cause of locking was unusual and was not discovered until the metacarpophalangeal joint was opened surgically.

FIG. 1

FIG. 2

Fig. 1: Preoperative photograph of the left hand, showing the deformity of the index finger during locking of the metacarpophalangeal joint in flexion.

Fig. 2: Roentgenogram of the left hand. The arrow points to the volar projection of the head of the second metacarpal on which the intra-articular membrane would catch.

CASE REPORT

M.H., a housewife, forty-eight years old, who did part-time work as a school cook, sought relief from a painful locking of the left index finger, a condition of a recent onset, with no history of injury. She stated that the finger seemed to get caught in the flexed position, from which she could not extend it. The locking was painful and disabling; it would come on suddenly, without apparent cause, usually while she was working. Later, and without obvious reason, the joint would unlock itself. She had always been double jointed in all finger joints, but the locking of the index finger was of recent onset.

The patient had normal, flexible hands. The index finger of the left hand would lock in semi-flexion at the metacarpophalangeal joint, without apparent cause. The joint could be unlocked by distraction and torsion of the finger, after which full extension was possible. A tendency to double jointedness and recurvatum deformity at the proximal interphalangeal joints of all fingers was noted; this was most marked in the left index finger. Roentgenograms of the hand were normal.

Despite its somewhat atypical features, the condition was thought to be a trigger-finger. On November 15, 1956, the fibrous flexor-tendon pulley was incised at its proximal end in the usual manner, through a palmar incision. After this, there was no relief of symptoms.

After failure to find the cause of the difficulty in the flexor-tendon mechanism, the extensor-tendon mechanism became suspect. As stated before, there was a tendency to hyperextension deformity in all the proximal interphalangeal joints, but this was most marked in the finger which

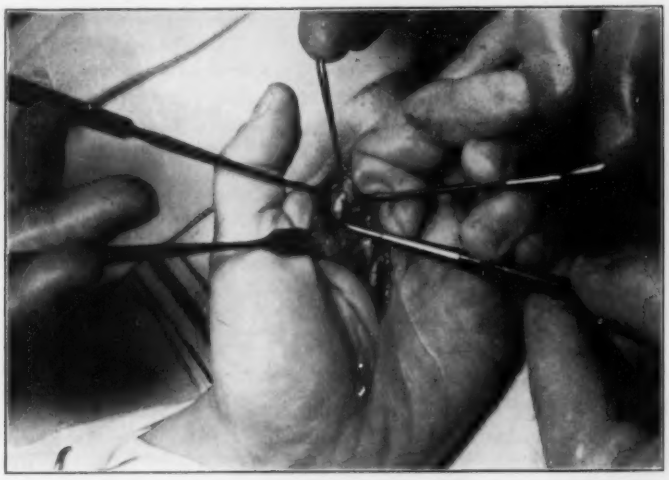

FIG. 3

Photograph showing surgical exploration of the second metacarpophalangeal joint. The tip of the dissecting probe (lower right) is under the edge of the crescentic intra-articular membrane.

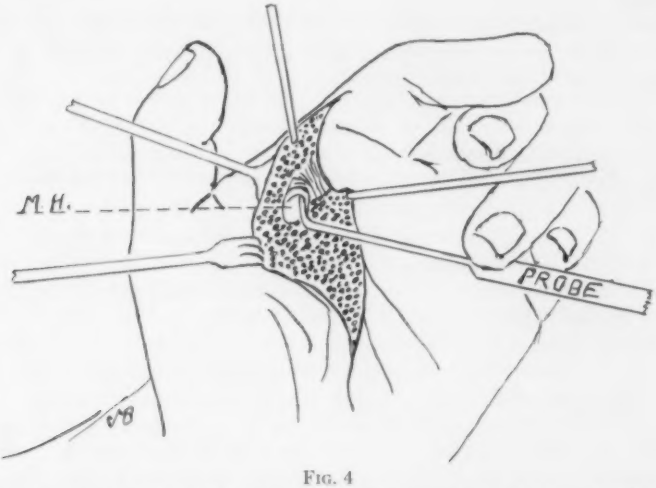

FIG. 4

Diagrammatic sketch showing detail from Fig. 3. The tip of the probe is under the crescentic fibrous structure. (*M.H.* = metacarpal head.)

became locked at the metacarpophalangeal joint. A deformity at the metacarpophalangeal joint analogous to the deformity at the proximal interphalangeal joint caused by buttonhole rupture of the extensor tendon was suggested as a possible cause of the locking. On February 23, 1957, the extensor-tendon mechanism was explored, with negative findings. Symptoms continued as before.

In October 1958, a case of locked index finger was reported by Flatt, in which an abnormal anatomical relationship between a sesamoid bone and the metacarpal head resulted in impingement and locking. In another case reported in 1954 by Alldred, the collateral ligament of the metacarpophalangeal joint had been torn by trauma, and locking was caused by the proximal part of the ligament which had rolled up on itself in such a way that it caught around the head of the metacarpal, thus causing locking.

It was these case reports which led me to the conclusion that the cause of locking in the case being described must be intra-articular. There was no sesamoid bone present (whereas it was present in Flatt's case) and there was no history of trauma (whereas there was in Alldred's case).

On November 20, 1958, the metacarpophalangeal joint was explored through a palmar incision near the base of the index finger. All was normal externally, but when the joint capsule was opened, a thin, smooth, crescentic membrane was seen within the joint. This structure covered the metacarpal head like a hood when the joint was in acute flexion; when the joint was extended, the edge of the hood would catch on the prominent volar projection of the metacarpal head, preventing extension of the joint. This mechanism was repeatedly demonstrated while the joint was open. The crescentic membrane was excised, after which locking ceased. Histological examination showed the membrane to be purely fibrous tissue, with no cartilage.

Since the last operation, the patient has been completely free of her former symptoms, has full range of motion in the affected joint, and is able to use her hand normally.

DISCUSSION

The nature of the crescent-shaped fibrous structure found in this metacarpophalangeal joint is unknown, nor is it clear why this structure first began causing trouble when this woman was forty-eight years old. However, it is surmised that this structure represented a portion of the volar accessory ligament or volar plate which had been torn during forgotten trauma and folded back on itself, in such a way that it would catch on the prominent metacarpal head during acute flexion of the joint.

This case is reported because it illustrates locking of a finger, due to internal derangement of the metacarpophalangeal joint; previous accounts of this phenomenon appear to be exceedingly rare.

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Undergraduate Teaching in Orthopaedic Surgery

THE COMMITTEE ON UNDERGRADUATE TEACHING; THE COMMITTEE ON EDUCATION *
THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Committee on Undergraduate Teaching was appointed in 1958 by the President of The American Academy of Orthopaedic Surgeons to consider and make recommendations regarding the teaching of orthopaedic surgery in medical schools. The appointment of this Committee was an expression of the great interest of the Academy in the teaching of orthopaedic surgery and of the conviction of the Academy that the ills of the neuromusculoskeletal system have attained increasing importance in the total field of medicine. The need for concern about the teaching in this area had been emphasized by earlier reports [1,2].

As a major part of its activity the Committee developed a questionnaire which was designed to obtain information about current teaching and to solicit comments and recommendations regarding the best methods of teaching and the ideal curriculum. This questionnaire was circulated to the chairmen of the departments of orthopaedic surgery of all medical schools in the United States. The objectives of the questionnaire might be listed as follows:

1. To determine the number of teaching hours and the techniques employed in the various schools, as well as to analyze current teaching programs.

2. To stimulate the orthopaedic departments in the various schools to evaluate their own teaching programs in relation to the total curriculum of the school.

3. To obtain criticisms and recommendations from the heads of various departments of surgery regarding the teaching of orthopaedic surgery with particular reference to the number of teaching hours, methods of teaching, and the place of orthopaedic surgery in the total programs of surgical teaching.

4. To enable the Committee to consider undergraduate teaching with a background of information and suggestions provided by the questionnaire.

Replies were received from sixty-four of the seventy-eight schools to which the questionnaires were sent. Three of these were two-year schools, leaving sixty-one to be considered in connection with the four-year curriculum.

These questionnaires were studied in detail by the Committee as a whole and by subgroups of the Committee. The material received had the usual deficiencies found in all questionnaires. Some answers were of dubious value and others had voids in various areas, but, on the whole, the questionnaires were very informative. They were particularly valuable as sources of background information for the deliberations of the Committee.

OBJECTIVES IN TEACHING

One question in the questionnaire was, "What is your philosophy regarding the objectives in teaching orthopaedic surgery to undergraduates?" In fifty-five of the sixty-one questionnaires there were specific answers. Of these, thirty-four respondents emphasized that the instruction in orthopaedic surgery should stress basic principles; thirty-four respondents stressed the importance of diagnostic

* Guy A. Caldwell, M.D. (1958)
Eldon G. Chuinard, M.D. (1958–59)
Carroll B. Larson, M.D.
H. Relton McCarroll, M.D.
Robert D. Ray, M.D.
Fred C. Reynolds, M.D.
Thomas D. Brower, M.D. (1960)
J. William Hillman, M.D. (1960)
William T. Green, M.D., *Chairman*

considerations; a lesser number mentioned the importance of the teaching of principles of treatment; and many emphasized that instruction in fractures should be sufficient to provide the student with a practical approach to such injuries. A statement was made by several respondents that the yardstick in teaching should be the teaching of "those things that a general practitioner should know about this field". Some individual statements as to the scope of teaching might be quoted: "so that the student would understand the problems involved, their recognition and management"; "basic principles of diagnosis and treatment"; "basic physiology and pathology as applied to the problems of orthopaedics and fractures"; "standard diagnostic procedures and principles of differential diagnosis related to the musculoskeletal system"; "techniques for handling common fractures"; "the common orthopaedic problems and general principles of treatment, not the details, of surgical procedures"; "concepts of rehabilitation"; "to teach an impartial balance between general principles and specifics"; "fundamental behavior of neuromuscular and skeletal diseases"; and "fractures and trauma".

After study of the answers to the questionnaire, the Committee concluded that the following should be the objectives of teaching orthopaedic surgery:

1. To teach orthopaedic surgery not in terms of a specialty, but rather to convey to the student a knowledge and understanding of the neuromusculoskeletal system in proportion to its importance in medicine and to the extent necessary for the student to develop a balanced concept of the human body and its disorders.

2. To impart an understanding of the basic responses of the neuromusculoskeletal system; to delineate the normal and the abnormal; and to teach the basic principles of diagnosis and treatment.

3. To convey facts regarding the more common conditions encountered in orthopaedic surgery and at all times to cultivate the "scientific approach" in the student.

4. To teach the student the cardinal principles of the treatment of trauma and fractures and, in so doing, to give him a more detailed understanding of the treatment of certain simple fractures to illustrate the general tenets.

5. To present to the student the total picture of physical disability, chronic disease, and rehabilitation.

6. To emphasize general principles in all areas and also to teach the specifics which all men in medicine should know.

7. Finally, to develop in the student the curiosity and respect for the problems in this field which their significance warrants.

CURRENT PRACTICES

First Two Years

Of the sixty-four orthopaedic departments from which replies were received regarding the curriculum of the first two years, there were ten which did not participate at all in the teaching during this period. Thirty-four participated in the instruction of the first year, and thirty did not, whereas in the second year, fifty participated and fourteen did not. The teaching by orthopaedic surgeons during these first two years was most irregular, and more difficulty was encountered in classifying this material than that material encompassed in the third and fourth years. Included in the exercises of the first year were such activities as "introductory lectures" in nine schools, averaging just over two hours, "teaching of anatomy" in seventeen schools, averaging six and one-half hours, and "correlation conferences or clinics" in two schools for an average time of four hours.

In the second year, the most constant activity of an orthopaedic department was participation in the teaching of physical diagnosis. This occurred in forty-one

schools. In most of these, however, this instruction seemed to be largely by lecture and demonstration to the whole class, and in only a few was the teaching given to small groups. Lectures were given by the orthopaedist in eight schools for an average total time of three hours on such subjects as "pathology", "growth and physiology of the skeleton", and "bone and bone repair". In seven schools a significant number of lectures was given on orthopaedics and fractures. Of these schools, four had a series of lectures on fractures, averaging just under seven hours, and three had a series of lectures on orthopaedic subjects averaging twenty-eight hours. In one school the Orthopaedic Department participated in "correlation clinics", with twelve hours devoted to these conferences, along with the representatives of other departments. In the first and second years there were fifteen departments which were concerned with the teaching of first aid for an average time of approximately four hours.

TABLE I

NUMBER OF SCHOOLS WITH ORTHOPAEDIC TEACHING IN THE THIRD AND FOURTH YEARS

(Based on Sixty-one Schools)

	Third Year	Fourth Year
No teaching	7	4
Teaching	54	57
Fractures only	6	1
Orthopaedics only	7	9
Combined	41	47

TABLE II

TYPE OF INSTRUCTION IN ORTHOPAEDICS IN THIRD AND FOURTH YEARS

(Average Hours)

	Third Year	Fourth Year
Lectures, entire class	15.0	5.6
Lectures, small groups	7.0	12.0
Clinical demonstrations	5.0	
Entire class		1.3
Small groups		3.4
Clerkships	17.0	22.0
Out-patient clinics	6.0	22.0
Ward rounds	4.0	9.0
Total hours	54.0	75.3

The average total time of teaching was two and three-tenths hours in the first year and ten and three-tenths hours in the second year (Table V).

Third and Fourth Years

Third-year teaching and fourth-year teaching were considered separately and then in combination. There was great variation in the individual schools as to what was taught during each of these years. Hence, the most significant assessment was that based on the combined teaching in the two years.

Third Year

Fifty-four of the sixty-one schools gave instruction in orthopaedics and fractures in the third year (Table I). In forty-one of these, both orthopaedics and

fractures were taught; in seven, only orthopaedics; and in six, only fractures were covered.

The type of teaching exercises and the size of the groups of students were considered, and the averages were recorded (Table II). In eight schools the teaching was restricted to the whole class; in twelve, instruction was restricted to small groups; and thirty-four schools utilized both small-group and whole-class teaching. Thirty-three of the schools stated that during the third year the student had some clinical participation. The average number of hours of student instruction in all schools for the third year was fifty-four (Table II).

The heads of departments were asked to rate their own teaching programs (Table III). Four rated their third-year programs as *excellent*, twenty-five as *good*, twenty as *satisfactory*, and eight as *inadequate*. This rating was very closely related to the number of hours of instruction. Those rating their own courses as *excellent* had an average of 110 hours; those who rated their programs as *good* had an average of sixty-six hours. Of those who rated their programs as *satisfactory*, the average was forty-eight hours. Of the eight who rated their third-year programs as *inadequate*, the average number of teaching hours was just under fourteen. Four schools did not rate their own programs. It is worthy of comment that in the twenty-eight schools that did not have clinical participation during this year, many of the instructors were entirely satisfied with this status.

TABLE III
RATING BY HEAD OF DEPARTMENT OF OWN PROGRAM

	Third Year		Fourth Year	
	No. of Depts.	Average Hours	No. of Depts.	Average Hours
Excellent	4	110	8	142
Good	25	66	28	96
Satisfactory	20	48	11	59
Inadequate	8	14	10	38
Not reported	4		4	

Fourth Year

Of the sixty-one orthopaedic departments, fifty-seven participated in the teaching of fourth-year students (Table I). General orthopaedics and fractures were taught by forty-seven. Nine taught orthopaedics only, and one taught fractures only. The teaching methods in the fourth year were analyzed (Table II). In four schools the teaching was confined to the entire class, whereas in thirty-one schools the instruction was given to small groups only, and in twenty-two the instruction was given to both small groups and the whole class. In the fourth year, thirty-seven schools had the students serve as clinical clerks on hospital wards, thirty-nine had students working in the orthopaedic out-patient clinic, and in thirty-four the students went on conducted ward rounds. On the average, each senior student received approximately seventy-five hours of exposure to orthopaedics.

When the department heads rated their fourth-year teaching, eight classified their courses as *excellent* (Table III); they had an average number of teaching hours of 142. Twenty-eight rated their courses as *good*; they had an average of just under ninety-six hours. Eleven rated their programs as *satisfactory*, with an average number of fifty-nine hours. Ten rated their programs as *inadequate*, with an average number of thirty-eight hours. Two of the schools had no teaching of fourth-year students except in elective courses. One had no clinical program, two

had out-patient clinical work only, one had lectures only, and in one school only a portion of the class received orthopaedic instruction.

No school rated both its third-year and fourth-year programs as *excellent*. Three schools rated their junior year as *excellent* and their senior year as *good*. These schools had an average number of 114 hours in their junior year and ninety-three in their senior year, a combination of 207 hours. Four rated their senior year as *excellent* and their junior year as *good*. These schools had an average of eighty-nine hours in their junior year and 110 in their senior year, a total of 199 hours. Fourteen schools rated both their junior and senior years as *good*, and their average hours were seventy-eight in the junior year and seventy-four in their senior year—a total of 152 hours.

It was particularly difficult to assess accurately the teaching of fractures and trauma. In the sixty-one schools that replied, fracture teaching was performed by orthopaedists in fifty-eight, by general surgeons in two, and in one school the teaching was divided equally between orthopaedists and general surgeons. In the fifty schools in which the number of hours of teaching could be tabulated, the average reported was twelve and seven-tenths. Thirteen schools had less than ten hours, twenty-five were in the range between ten and twenty hours, and eight had more than twenty hours. The number of hours devoted to the teaching of trauma was hard to determine, since instruction was given while the students were clinical clerks, while they worked in the out-patient clinics, and during ward rounds in various departments, particularly in general surgery. The teaching in musculoskeletal trauma was performed by orthopaedists in fifty-five of the sixty-one schools; in four the teaching of trauma by orthopaedic surgeons was limited to the teaching of fractures. In the two schools, as mentioned, orthopaedists were not concerned with fractures or any phase of trauma.

One question in the questionnaire concerned the use of the "team approach" in the teaching of trauma. Of the forty-eight schools responding on this point, nineteen used what they considered to be such an approach, and twenty-nine did not. As a related question, inquiry was made whether students were assigned to the emergency room. Of the sixty-one schools, forty-seven did assign students to such a service, and ten did not. Four did not answer this question.

CONCLUSIONS AND RECOMMENDATIONS

Certain conclusions and general recommendations were formulated by the Committee in its deliberations after reviewing the questionnaires. These recommendations were made on the premise that the objective in the teaching of orthopaedic surgery, stated simply, is to give the student basic concepts, understanding, and knowledge in this area of surgery in proportion to its importance in the total field of medicine and in the balanced education of the student.

The first recommendation was that more emphasis should be placed on the neuromusculoskeletal system in the first two years, by devoting attention to it in the teaching of the basic sciences and by providing more teaching by orthopaedic surgeons. Particularly needed is an increased correlation of the activities of the teachers of basic sciences and of orthopaedic surgery. Orthopaedic surgery and its principles represent excellent areas for the teaching of fundamental biological reactions and the scientific approach.

In the first year, at least eight hours should be assigned to orthopaedic surgery (Table V). Most of this time should be related to anatomy, with patients used to illustrate the function of the musculoskeletal system in a graphic way. In addition, teaching programs correlated with physiology and biochemistry would be highly desirable. Programs of this type would increase the value of teaching in anatomy,

in physiology, and in biochemistry, as they affect the neuromusculoskeletal system and, in turn improve the teaching of orthopaedic surgery.

In the second year, twenty hours seems to be the minimum assignment which should be given to orthopaedic surgery (Table V). This should include ten to twelve hours of physical diagnosis taught by orthopaedic surgeons. Ideally, most of this instruction should be carried out in small sections of three or four students per instructor. A preliminary demonstration in physical diagnosis of one and one-half hours in length can be given to a large group very effectively. In these teaching exercises the student first becomes acquainted with the diagnostic procedures used for neuromusculoskeletal disease and with the patient. Also in the second year, lectures and lecture demonstrations to the whole class on the basic phenomena and responses of the musculoskeletal system are recommended on such

TABLE IV

RATING BY HEAD OF DEPARTMENT OF OWN PROGRAM
(Combined Third-Year and Fourth-Year Program in Excellent and Good Categories)

Rating			Average Hours		
Third Year	Fourth Year	No. of Depts.	Third Year	Fourth Year	Total Hours
Excellent	Excellent	0	0	0	0
Excellent	Good	3	114	93	207
Good	Excellent	4	89	110	199
Good	Good	14	78	74	152

TABLE V

CURRICULAR HOURS OF TEACHING OF ORTHOPAEDICS

School Year	Current Average	Proposed Minimum
First	2.3	8
Second	10.3	20
Third	54.0	78
Fourth	75.0	80
Total hours	141.6	186

subjects as the reactions of bone, skeletal growth and development, the neuromuscular system and its responses, factors producing deformity, and basic concepts of therapy in relation to the musculoskeletal system. Eight such lectures and lecture-demonstrations represent a minimum number. Interdepartmental correlated teaching exercises should be encouraged with pathology, bacteriology, and other departments. In those schools which give training in orthopaedics to a small group of students throughout the third year, it would be highly desirable to give many of the lectures now given in the third year during the last part of the second year. In this way, each student would have the same basic background of exposure to orthopaedics at the time he begins his work within a small group.

In the third and fourth years the patient and his diseases are emphasized. The actual distribution of time and assignments between the third and fourth year depends on the general curriculum. A program for the teaching of orthopaedics during these two years which we favor would include seventy-eight hours of instruction during the third year and two weeks of clinical clerkship (eighty hours) during the fourth year (Table V).

The details of teaching and the type in the third and fourth years must

depend necessarily on the curriculum and on such factors as the size and attributes of the teaching staff and the number of hours that can be made available. One scheme that was proposed for the third year involves a certain number of lecture-demonstrations and symposia for the whole class, totaling somewhere in the neighborhood of eighteen to twenty hours. These exercises would cover all areas of orthopaedic surgery, including fractures, and incorporate such areas as rehabilitation and the general responsibilities involved in the care of the physically handicapped. As an example, an afternoon devoted to a symposium on trauma is recommended, in which the various departments participate in a combined exercise. The remainder of the time in the third year would be devoted to small-group teaching with supervised experience in dealing with patients in the out-patient clinic and on the ward and including both children and adults. How much of the teaching is done to small groups depends on the size of the faculty and various other factors in the total curriculum. Ideally, the greater part of the teaching in the third year should be small-group instruction with the intimate, direct participation of the student.

In the fourth year, it is recommended that the student should be assigned for two weeks to the Orthopaedic Service as a clinical clerk. He would live with the Service and participate in its activities in a complete way. Two weeks seems to be the most that orthopaedics can demand, but an ideal plan would be a combined assignment to orthopaedic surgery and the emergency room for four weeks, during which two weeks would be allocated to orthopaedic surgery. This would permit a rotation of assignments enabling the students to participate in night coverage in the emergency room. At the end of his medical-school experiences the student should have enough understanding of fractures and trauma to meet the medical emergencies that any physician may be called on to face. A clinical clerkship in orthopaedic surgery for every medical student is considered highly desirable; in our time schedule this should be for eighty hours.

Details of any curriculum depend on particular problems of the school. It does seem that 186 hours is the minimum amount which will permit adequate instruction, and it appears that from 200 to 220 hours would be an ideal assignment. However, it should be emphasized that it is not just the number of hours but the way that these hours are used that counts. The time of the students must be used effectively, and the techniques of teaching should be constantly re-evaluated.

The need for aids in undergraduate teaching was emphasized by many in the questionnaire. Most of our motion pictures in orthopaedic surgery are geared for graduate instruction, and most are of operative procedures. The Committee recommends that The American Academy of Orthopaedic Surgeons give cons'deration to the need for motion pictures and other aids geared for the teaching of undergraduates, and that the Academy consider either developing such aids or fostering their development. Motion pictures which are specifically designed for the undergraduate student would fill a great need provided they were expertly done. Included might be such subjects as the basic responses of bone, of joints, and of muscle, including their reaction to trauma and disease; the orthopaedic examination; and the presentations of various specific neuromusculoskeletal subjects, emphasizing physical findings, diagnostic considerations, and general therapeutic principles. The Academy might add such films to its library for distribution and make arrangements for the sale of duplicates to the schools on demand. Aids which increase the efficiency of teaching are certainly needed, although it is to be emphasized that the patient is the best teaching aid of all.

Finally, the Committee is impressed by the great need for strengthening

the programs in many schools. The first step in this regard is for each department to do a better job under its present circumstance. Then it should make persistent constructive efforts to develop the proper place of orthopaedics in the total curriculum of its school. More interest in teaching itself, exploration and improvement of techniques of instruction, closer relation with the other departments, and more interdepartmental exercises are some of the paths that should be followed. Teaching should be the primary interest of a department of orthopaedics, and, indeed, of a medical school. Let us conclude by stating that nothing takes the place of a stimulating teacher.

REFERENCES

1. Gill, A. B., *Chairman:* A Conference of Teachers of Orthopaedic Surgery. (Conducted at the Joint Meeting of The American Orthopaedic Association, The British Orthopaedic Association, and The Canadian Orthopaedic Association. Quebec, Canada, June 5, 1948.) J. Bone and Joint Surg., **31-A:** 203–218, Jan. 1949.
2. Green, W. T.: Orthopaedic Surgery, Yesterday and Tomorrow. J. Bone and Joint Surg., **39-A:** 675–685, June 1957.

Proceedings

CLINICAL ORTHOPAEDIC SOCIETY

The Forty-eighth Annual Meeting of the Clinical Orthopaedic Society was held in Milwaukee, Wisconsin, October 20 through 22, 1960, under the Presidency of Dr. Fred C. Reynolds, St. Louis, Missouri. Dr. David J. Ansfield was *Chairman* of the Local Committee; Dr. Frederick G. Gaenslen, of Milwaukee, arranged the Program.

Officers elected for the coming year are: *President:* Charles H. Frantz, M.D., Grand Rapids, Michigan; *Vice-President:* Marvin P. Knight, M.D., Dallas, Texas; and *Secretary-Treasurer:* Lyman Smith, M.D., Elgin, Illinois. The 1961 meeting will be held in Dallas, Texas.

The Program consisted of clinical presentations by the local group of orthopaedists and included the following:

Fracture-Dislocation of the Talus. Dr. David J. Ansfield[1] presented a patient who had been treated by fusion of the calcaneus to the tibia. The patient, who had been operated on seven years before, was seen to walk without any perceptible limp and stated that he was free from pain. The functional result was excellent. Dr. Ansfield also presented another patient, a woman who had sustained an undisplaced fracture of the femoral neck. The fracture had been treated conservatively by non-weight-bearing. Full recovery ensued in three months, but three years later, aseptic necrosis of the femoral head had developed, with collapse of the femoral head, as shown by roentgenogram. When this patient was presented, seven years after injury, she had marked loss of motion but practically no limp and very little pain. No treatment seemed indicated.

Displacement Osteotomy of the Hip. Dr. Walter Blount[2] presented six patients who had been treated with displacement osteotomy of the hip for degenerative joint disease and aseptic necrosis of the femoral head. He advised preoperative tracings of the femur, indicating location and angle and amount of displacement of the osteotomy. The procedure was done under roentgenographic control, and internal fixation was employed, using a straight V-shaped osteotomy plate. The patients got about with crutches within a few days of the surgery, and active motion of the joints of the involved extremity was encouraged. The patients who were presented showed good results. Dr. Blount emphasized that if an osteotomy is to be successful, the hip should have 70 degrees of flexion. If there is a diminished range of hip flexion, the extremity should be placed in approximately 60 degrees of external rotation in order to allow the patient to put on his own shoes. Dr. Blount also showed a movie with preoperative findings and postoperative results.

Ochronosis and Alkaptonuria. Dr. J. Howard Johnson[3] showed two patients with ochronosis and alkaptonuria. The first patient had severe degenerative arthritis involving the hips and knees. A Judet arthroplasty had been done, and marked discoloration of the articular cartilage of the hip was demonstrated. This procedure was performed in 1943, but, in 1955, the prosthesis had fractured and had been replaced with an Austin Moore prosthesis, with a successful result. The second patient showed marked degenerative arthritis of the knee which had been treated by débridement arthrotomy.

Pyrford Arthrodesis of the Hip. Dr. Peter Carnesale[4] and Dr. Joseph R. Stone[5] presented twenty-six cases of Pyrford arthrodesis of the hip (intra-articular fusion with internal fixation and subtrochanteric osteotomy). There was one failure of fusion and three non-unions of the osteotomy site, requiring further operative procedures. Some five-year end results were shown, details of postoperative care were described. Two patients with successful shoulder fusion in which they had utilized the principle of osteotomy below the joint to relieve strain at the fusion site were also presented.

Subtalar Fusion. Dr. Chester C. Schneider[6] showed his technique of subtalar fusion. A dowel bone graft was taken from the tibia and introduced obliquely downward and outward through the neck of the talus, crossing the subtalar joint into the calcaneus. The end results that were demonstrated were excellent.

1. 208 East Wisconsin Avenue, Milwaukee 2, Wisconsin.
2. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
3. 161 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
4. Veterans Administration Center, Wood, Wisconsin.
5. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
6. 231 West Wisconsin Avenue, Milwaukee 3, Wisconsin.

Hemangio-endothelioma of the Humerus. Dr. Frederick G. Gaenslen [7] presented an unusual case of hemangio-endothelioma with extensive involvement of the proximal end of the humerus in an eight-year-old boy. The tumor was resected, and a fibular bone graft was used with an intramedullary rod, but this was unsuccessful, and the procedure had to be repeated. At the second operation, because of extensive bleeding at the first operation, a clamp was placed on the axillary artery, and the tumor was successfully excised. Ten units of blood had been necessary for the first operative procedure, but no blood was used for the second.

Treatment of Drop-Foot. Dr. Albert C. Schmidt [8] presented excellent end results of the treatment of drop-foot by triple arthrodesis and posterior tibial bone block. This had been done for spastic as well as flaccid paralysis. The posterior bone block was a modification of the Campbell type.

Weight-Bearing Prosthesis for Lower Extremity. Dr. C. Hugh Hickey [9] presented patients who were using a weight-bearing prosthesis for the lower extremity. The proximal portion of the prosthesis was constructed like a bucket and was called a quadrilateral socket. The high anterior wall of the socket seemed to do much to improve stabilization.

Giant-Cell Tumor of the Calcaneus. Dr. Paul J. Collopy [10] presented a patient in whom he had resected the entire calcaneus because of involvement by a giant-cell tumor. The Achilles tendon had been attached to the plantar fascia. The patient's gait was remarkably good. Dr. Collopy also presented a patient with proved multiple myeloma of sixteen years' duration who had had multiple surgical excisions of the lesions.

Fibular Transplants in Tibial Fractures. Dr. John O'D. McCabe [11] showed patients with fractures of the tibia with marked bone loss who had been treated by fibular transplants. The procedures were done in patients in whom the defects in the tibia were large and in whom the skin over the anterior aspect of the leg was poor. The amount of hypertrophy of the fibula was remarkable. In several cases fatigue fractures had developed, but these healed well after immobilization.

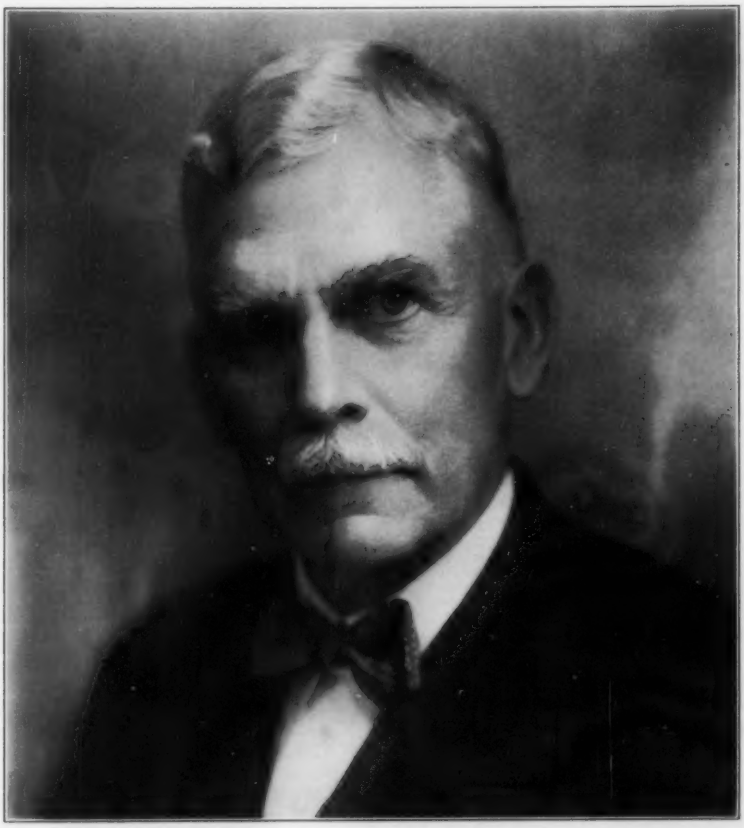
Comminuted Colles Fractures. Dr. Louis Kagen [12] presented several patients with comminuted Colles fractures in which the comminuted area was transfixed with a Steinmann pin drilled obliquely through the ulna. The end results shown were quite satisfactory.

Idiopathic Scoliosis. Dr. Robert H. Cassidy [13] showed that in cases of idiopathic scoliosis not severe enough to require surgery, he was able to control and, in some cases, lessen the deformity by having the patients continually wear a Milwaukee brace. The brace was demonstrated and commented on by Dr. Blount.

Recurrent Dislocation of the Shoulder. Dr. Bruce J. Brewer [14] presented three patients with recurrent dislocation of the shoulder. In all three there was a definite defect in the anterior portion of the glenoid fossa, as demonstrated by roentgenograms with special axillary views. The three patients had been treated efficiently by transplantation of the tip of the coracoid process into the defect, after the method described by A. J. Helfet.

Sprains of the Fibular Collateral Ligaments of the Ankle. Dr. Owen E. Miller [15] showed patients whom he had operated on for severe sprains of the fibular collateral ligaments of the ankle. The patients were chosen for surgery when examination under general anesthesia showed 10 degrees or more lateral tilt of the talus in the ankle mortise. Examination under anesthesia was performed when there was severe swelling, marked tenderness, or both, on the lateral aspect of the ankle.

7. 1031 North Astor Street, Milwaukee 2, Wisconsin.
8. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
9. 4611 North Oakland Avenue, Milwaukee 11, Wisconsin.
10. 161 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
11. 945 North 12th Street, Milwaukee 3, Wisconsin.
12. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
13. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
14. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.
15. 2040 West Wisconsin Avenue, Milwaukee 3, Wisconsin.



JOEL ERNEST GOLDTHWAIT

1866 — 1961

Rarely has one individual had the opportunity to observe, to contribute to, and to influence the progress of orthopaedic surgery so greatly and for so long a period of time as did Joel Ernest Goldthwait. He was born in Marblehead, Massachusetts, on June 18, 1866, and received his early education in the schools of Marblehead. He then entered the Massachusetts Agricultural College, planning to spend his life in scientific agriculture. While in college he was influenced greatly by Dr. Charles Bull, who was Professor of Botany and also physician to the students. Dr. Goldthwait assisted both in the laboratory and in the care of the students. This aroused his first interest in medicine.

After graduation, one unhappy day in business convinced him that the market place was not for him. He entered the Harvard Medical School, graduating in 1890. He became an intern at the Boston Children's Hospital, followed by internship at the Boston City Hospital where he came under the influence of Dr. Edward H. Bradford, who was the leading orthopaedic surgeon in Boston. After completing his internship, he engaged in general practice in Boston, becoming Assistant Surgeon at the Children's Hospital and Visiting Orthopaedic Surgeon to the House of the Good Samaritan. He became interested in the new specialty of orthopaedic surgery and became a member of the young American Orthopaedic Association in 1893.

At the turn of the century no hospital in Boston had facilities for the care of the crippled and disabled after the age of twelve. Dr. Goldthwait's pleas for the continued care of these unfortunates for a long time went unheard. Finally, he was given a third-floor room at the old Carney Hospital, where he started the first clinic for adult cripples in America. Many of these cripples became better and returned to lives of usefulness. When the results of this work became known, the Massachusetts legislature voted $10,000 for the establishment and maintenance of a clinic for the care of the adult cripple. In 1899 he organized an orthopaedic out-patient service at the Massachusetts General

Hospital and became its first chief. It soon became apparent that in-patient as well as out-patient care was necessary for the rehabilitation of many of these unfortunate people. Dr. Goldthwait raised the sum of $75,000 among his patients and friends for an orthopaedic ward at the Massachusetts General Hospital. This was built in 1909, and he became its first head.

The Robert Breck Brigham Hospital opened its doors in 1914 for the care of those citizens of Boston who were prevented by physical disability from earning a livelihood. Dr. Goldthwait, one of the original trustees, guided the hospital into the treatment of patients suffering from chronic arthritis. In his efforts to salvage the physically unfit he realized that more was required than the usual medical and orthopaedic care. He began to study postural deformities and to devise measures for preventing and correcting them. These studies were summarized in his Shattuck Lecture presented to the Massachusetts Medical Society in 1914. During this period he studied spine disabilities and demonstrated that the sacro-iliac joint was a true articulation and not a synarthrosis, as had been previously taught. A workable classification for chronic arthritis was devised which is still of practical value.

With the outbreak of World War I a preparedness committee was appointed by The American Orthopaedic Association and by the orthopaedic section of the American Medical Association. Dr. Goldthwait was Chairman of this committee in 1916. When a call came for orthopaedic surgeons from Sir Robert Jones, a personal friend of long standing, he was ready and sailed to Liverpool with twenty orthopaedic surgeons within four weeks. In the following three months he brought sixty more orthopaedic surgeons to England. When the United States entered the war in 1917 he was named Chief of the orthopaedic section of the American Expeditionary Force with the rank of Major. He was promoted to Colonel and served with the army for twenty-two months. He was mustered out with the rank of Brigadier General. For many years after the war he served as an instructor at the War College.

After his return to civilian life he was instrumental in the establishment and encouragement of ancillary medical services, particularly the Bouvé-Boston School of Physical Education and the Boston School of Occupational Therapy. His interest in young people induced him to accept a professorship at Smith College where he organized a department of physical education. During this busy life he found time to write many medical papers and several books. He gave inspiration, instruction, and counsel to a large number of younger orthopaedic surgeons. He gave generously of his time and money to numerous civic projects. Sir Wilfred Grenfell, a patient and friend, was given a hospital ship for the Labrador Mission. Berea College was given an Agricultural Building. A large tract of wooded land, which he had developed in Medfield, Massachusetts, was given to the Trustees of Reservations to be used as a park.

Many honors came to him. He was an early member of The American Orthopaedic Association and helped to shape its policies and ideals. In 1914 he was one of the founders of the American College of Surgeons, and later of The American Academy of Orthopaedic Surgeons. He was given honorary membership in The British Orthopaedic Association. At the end of World War I he was awarded the Distinguished Service Medal. The British Government made him a Companion of the Order of St. Michael and St. George. In 1949 Massachusetts State College conferred upon him the degree of Doctor of Laws. Berea College, of which he was a trustee for many years, gave him the degree of Doctor of Science (*honoris causa*) in 1951.

Dr. Goldthwait was a pioneer in things medical. Medical literature contains many firsts which he introduced: in the surgery of the knee, in the treatment of paralytic deformities, in the understanding of disabilities of the low back, and in the appraisal and treatment of the chronically ill. His vision and his courage in setting out on new paths were an example to his contemporaries and an inspiration to those who followed him. In his earlier years he tried to prevent, as well as to correct, deformities by surgical methods. Later, he realized that most of his medical problems were concerned with deformities of the whole body. For such deformities he coined the term *faulty body mechanics*. His efforts were directed to the treatment of the whole patient, not only the disease. His interest in things medical continued until the end. He gave many valuable suggestions for improvement in medical care and in basic orthopaedic surgery in particular. He died of a coronary thrombosis on January 15, 1961.

J.G.K.

RUSSELL ALSFELDER

1918-1960

Russell Alsfelder died on December 22, 1960, at the age of forty-two, after an acute illness of three days. He had practiced orthopaedic surgery for ten years, following an eight-year postgraduate struggle to gain Board qualification. His unstinting efforts to provide orthopaedic care to a small industrial community is, probably, of little general interest, and his passing worthy of only local mention. Yet the persistent, stubborn courage of his exhausting struggle against mounting physical odds makes his brief life uniquely significant to his medical confreres. And the manner of his death is particularly meaningful to his fellow orthopaedic surgeons.

Russ was a tough-luck guy who somehow never became completely discouraged. Medicine early became a jealous mistress who made increasing demands far exceeding his physical reserves. A backstrain, incurred in lifting a patient while he worked as an orderly during his premedical days, ironically set the pattern of his subsequent career and death. Disqualified for military service because of undiagnosed "neurotic" back complaints, Alsfelder encountered difficulty in gaining approved training in the specialty toward which his ailment guided him. This training period was repeatedly interrupted and prolonged by many myelograms and two unsuccessful laminectomies. And through circumstances quite beyond his control he was unable to gain any Board recognition for the years spent in the New York City phase of his training.

Despite continuing disability and discouraging delay, Russ was able to resume his training in his home state of Ohio, completing his qualifications in Columbus in 1951 and becoming Board certified two years later. During this phase of his effort his back disability became manifest as rheumatoid spondylitis which responded favorably to repeated roentgen therapy. Although this relief enabled him to carry his share of a busy partnership in Hamilton, Ohio, the amount of therapeutic and diagnostic x-ray exposure soon depressed his white cells and platelets and required prolonged therapy to control a bleeding diathesis. With relief denied him after roentgen therapy, Russ turned to steroids for relief of his spinal and more recent peripheral joint complaints. He was all

too well acquainted with the dangers which lay in this therapy, but his loyalty to his practice and concern for his wife and five children forced him to disregard the warnings and advice of his friends and consultants. Few of his colleagues realized the magnitude of this courageous battle as he recently completed two terms as Secretary of the Ohio State Orthopaedic Society and in October received membership in the Clinical Orthopaedic Society.

Intensifying this struggle was a strong, forceful, tense, and generous personality dedicated to a code of ethical and professional standards which few could attain. A sharp wit and delightful humor penetrated all sham and shortcomings with predictable and often explosive results. While tolerating no self-pity or complaints, his singular insight into suffering and disease earned him the respect and devotion of a host of grateful patients. His lifelong dedication and devotion to medicine left little time for pleasures other than those he gained from his home and young family.

Lacking the resistance of normal bone marrow and functioning adrenals, he was thrown into profound shock by an attack of pneumonitis. Heroic therapeusis could not revive him. A consistent epitaph to this ill-fated career would be his own proud observation that now, since his children's future seemed well secured, he could begin taking things a little easier in the practice of orthopaedic surgery.

C.U.H.

News Notes

The Annual Meeting of **The American Orthopaedic Association** will be held at Yosemite, California, May 22 through May 25, 1961. The following program has been arranged:

Monday, May 22

Traumatic Dislocation of the Hip. Army Experience and Results over a Twelve-Year Period.
Colonel Ernest A. Brav, Madigan General Hospital, Fort Lewis, Washington.
Discussors: Dr. Paul R. Lipscomb, Rochester, Minnesota, and Dr. Don King, San Francisco, California.

Indications, Techniques, Fundamentals, and Results of Osteotomies in Degenerative Arthrosis of the Hip.
Dr. Carlos E. Ottolenghi and Dr. Edgar Frigerio, Buenos Aires, Argentina.

Varus Producing and Derotational Subtrochanteric Osteotomy in the Treatment of Congenital Dysplasia of the Hip.
Dr. E. G. Chuinard and Dr. Norman Logan, Portland, Oregon.
Discussors (last two papers): Dr. Walter P. Blount, Milwaukee, Wisconsin, Dr. H. R. McCarroll, St. Louis, Missouri, and F. P. Dewar, Toronto, Canada.

Surgery of Tuberculosis of the Hip. Recovery or Retention of Mobility.
Dr. Ryosuke Katayama, Tokyo, Japan.
Discussor: Dr. David M. Bosworth, New York, N.Y.

Lymphangiosarcoma Arising in Chronic Lymphedematous Extremities. Report of Eleven Cases and Review of the Literature.
Dr. Mark B. Coventry, Dr. Edward H. Soule, and Dr. Howard F. Taswell, Rochester, Minnesota.
Discussors: Dr. J. Vernon Luck, Los Angeles, California, and Dr. C. Howard Hatcher, Palo Alto, California.

Introduction of the Exchange Fellows.

Tuesday, May 23

End Results of Patellectomy.
Dr. Francis E. West, San Diego, California.

Treatment of Displacement of the Proximal Radial Epiphysis.
Dr. John A. Reidy and Dr. George W. Van Gorder, Boston, Massachusetts.
Discussors (last two papers): Dr. Robert I. Harris, Toronto, Canada, Dr. Harrison McLaughlin, New York, N.Y., and Dr. Preston Wade, New York, N.Y.

Non-Union of the Femur Treated with Intramedullary Rod and Bone Graft.
Dr. Edward T. Smith, Houston, Texas.

Late Results of Battle Fractures of the Femur.
Dr. Joseph D. Godfrey, Buffalo, New York.
Discussors (last two papers): Dr. Leonard T. Peterson, Washington, D.C., Dr. William A. Larmon, Chicago, Illinois, and Dr. Milton S. Thompson, San Antonio, Texas.

Acromionectomy in the Treatment of Tendinitis of the Shoulder.
Dr. George Hammond, Boston, Massachusetts.
Discussors: Dr. Harrison L. McLaughlin, New York, N.Y., and Dr. Julius S. Neviaser, Washington, D.C.

Trends in Trauma.
Dr. Harrison L. McLaughlin, New York, N.Y. (Guest of Honor).

Wednesday, May 24

A Technique for Shoulder Arthrodesis.
Dr. Joe B. Davis and Dr. George W. Cottrell, Portland, Oregon.
Discussors: Dr. Joseph E. Milgram, New York, N.Y., and Dr. James E. Bateman, Toronto, Canada.

The Axillary Incision.
Captain Thomas J. Ryan, Major James T. Leslie, and Dr. Milton S. Thompson, San Antonio, Texas.
Discussors: Dr. Sam W. Banks, Chicago, Illinois, and Dr. Jesse T. Nicholson, Philadelphia, Pennsylvania.

The Effect of Growth Hormone on Healing of an Experimental Long Bone Defect.
Dr. Robert E. Zadek and Dr. Robert A. Robinson, Baltimore, Maryland.

The Vascularization of Fracture Calluses.
Dr. James B. Wray, Syracuse, New York.
Discussors (last two papers): Dr. Robert D. Ray, Chicago, Illinois, Dr. J. William Hillman, Nashville, Tennessee, and Dr. George W. Hyatt, Washington, D.C.
The Processes of Tendon Healing Within the Flexor Digital Sheath of the Dog.
Captain Austin D. Potanza, Washington, D. C.
Discussors: Dr. Walter C. Graham, Santa Barbara, California, and Dr. Joseph H. Boyes, Los Angeles, California.
Presidential Address. Dr. Edwin F. Cave, Boston, Massachusetts.

Thursday, May 25

The Failed Prosthesis and Its Surgical Management with Early Results in a Small Group of Cases.
Dr. Philip D. Wilson, Jr., New York, N.Y.
Discussors: Dr. Otto E. Aufranc, Boston, Massachusetts, and Dr. Fred C. Reynolds, St. Louis, Missouri.
Bilateral Iliac Osteotomy.
Dr. E. Harvey O'Phelan, Minneapolis, Minnesota.
Discussors: Dr. Theodore H. Sweetser and Dr. John H. Moe, Minneapolis, Minnesota.
Osteotomy of the Fused Scoliotic Spine.
Dr. Bruce J. Brewer, Milwaukee, Wisconsin.
Discussors: Dr. Joseph C. Risser, Pasadena, California, and Dr. Paul E. McMaster, Beverly Hills, California.
Mold Arthroplasty and the Bony Ankylosed Hip.
Dr. Morten Smith-Petersen and Dr. Otto E. Aufranc, Boston, Massachusetts.
Discussors: Dr. Carroll B. Larson, Iowa City, Iowa, and Dr. Carl E. Badgley, Ann Arbor, Michigan.
A Method for Replacement of the Anterior Cruciate Ligament of the Knee.
Dr. Don H. O'Donoghue, Oklahoma City, Oklahoma.
Discussors: Dr. Donald B. Slocum, Eugene, Oregon, and Dr. Carlo S. Scuderi, Chicago, Illinois.

Part I Examination of **The American Board of Orthopaedic Surgery** will be held on June 19 and 20, 1961, in Philadelphia, Pennsylvania; Nashville, Tennessee; and Palo Alto, California. The deadline for filing applications was January 1, 1961.

Part II Examinations, oral and written, will be given in Chicago, Illinois, on January 24, 25, and 26, 1962. The deadline for filing applications is July 1, 1961.

Inquiries should be sent to Dr. Sam W. Banks, *Secretary-Treasurer*, **The American Board of Orthopaedic Surgery, 29 East Madison Street, Chicago 3, Illinois.**

Kappa Delta Award—1961

The Committee on Scientific Investigation of The American Academy of Orthopaedic Surgeons announces that all manuscripts which are to be entered for the Kappa Delta Award, which is presented annually for the outstanding scientific contribution in the field of orthopaedic surgery and which carries an honorarium of $1,000, should be forwarded to the Chairman of the Committee, Dr. Charles H. Herndon, University Hospitals, 2065 Adelbert Road, Cleveland 6, Ohio, by June 15, 1961. The winner of the award will be asked to present the paper at the Annual Meeting of The American Academy of Orthopaedic Surgeons in January 1962. Therefore, it is suggested that the manuscripts be submitted as early as possible so that the utmost care may be given in evaluating each individual contribution.

The Board of Trustees of **Western Reserve University** upon recommendation of the Faculty of the School of Medicine has established an endowed chair in orthopaedic surgery at the University's medical school and elected its first incumbent, **Dr. Charles H. Herndon,** Cleveland, Ohio; Dr. Herndon is currently Professor of Clinical Orthopaedics at Western Reserve University. The Chair, to be known as the Rainbow Professorship, was made possible by a recent gift from Mr. and Mrs. George M. Humphrey to mark their long-standing interest in Rainbow Hospital for Crippled Children, its connection with University Hospitals of Cleveland, and its affiliation with the School of Medicine.

GORDON RESEARCH CONFERENCES

Chemistry, Physiology, and Structure of Bones and Teeth

July 10–14, 1961

Kimball Union Academy, Meriden, New Hampshire

William P. Norris, *Chairman*
Roy V. Talmadge, *Vice-Chairman*

July 10

Selected Communications.
Robert E. Rowland, *Chairman*.
Evolution of Bone as a Tissue.
Marshall R. Urist, *Chairman*.
Robert H. Denison: The Habitat of the Earliest Vertebrates.
Eric Stensio: The Skeleton of the Early Vertebrates.

July 11

Evolution of Bone as a Tissue (*Continued*).
Marshall R. Urist, *Chairman*.
Alfred S. Romer: Vertebrate Paleontology.
T. Dale Stewart: The Last Phase of Human Evolution.
Vasculature and Hemodynamics of Bone.
Robert B. Duthie, *Chairman*.
J. Trueta: Anatomical Considerations of Circulation.

July 12

Vasculature and Hemodynamics of Bone (*Continued*).
Robert B. Duthie, *Chairman*.
Donald A. McDonald: Hemodynamics of Blood Flow.
Friedrich Wassermann: The Problem of Transport between Blood and Bone.
James B. Wray: The Response of Periosteal Vessels to Certain Vasomotor Agents.

July 13

Physical and Chemical Reactions of Bone Mineral.
William F. Neuman, *Chairman*.
Speakers and subjects to be announced.
Eubert J. Daniel: Histochemical and Electron-Optical Analyses of Calcifying Systems: Part 1, Embryogenesis; Part 2, Maturation.
Howard M. Myers: Surface Properties of Apatite.
Aaron S. Posner: Calcium-Hydrogen Balance in Synthetic Biological Apatites.
Defects in Mineralization and in Mineral Reserve.
Robert P. Heaney, *Chairman*.
Robert Steendijk: Observations on Calcification Affected by Intravenous Administration of Inorganic Phosphate.
Leo Lutwak: Osteoporosis and Its Treatment, as Evaluated by Calcium-45.

July 14

Defects in Mineralization and in Mineral Reserve (*Continued*).
Robert P. Heaney, *Chairman*.
Jenifer Jowsey: The Structure of Bone in Relation to Age and Osteoporosis.
Eugene Eisenberg: Bone Formation and Metabolism in Relation to Osteoporosis and the Aging Process.

Requests for attendance at the conferences, or for additional information, should be addressed to W. George Parks, Director, Department of Chemistry, University of Rhode Island, Kingston, Rhode Island. From June 12 to September 1, 1961, mail for the office of the Director should be addressed to Colby Junior College, New London, New Hampshire.

The **First European Congress of Anesthesiology** will be organized by the Austrian Society of Anesthesiology in Vienna from September 3 to 7, 1962. The former Imperial Palace will serve as the meeting place. A preliminary program will be ready in the Autumn of 1961. For information, inquiries should be addressed to: Dr. Rudolf Kucher, *Secretary-General*, Postgraduate Medical School, 4 Alderstrasse, Vienna IX, Austria.

Book Review

MINERAL METABOLISM. AN ADVANCED TREATISE. VOL. I, PART A. PRINCIPLES, PROCESSES, AND SYSTEMS. Edited by C. L. Comar and Felix Bronner. New York, Academic Press Inc., 1960. $12.00.

Those of us who worked on mineral metabolism in the thirties welcomed the appearance of Shohl's monograph which presented a unified approach by one authority in the field, to a subject which was still relatively circumscribed. In the interim of twenty-one years this area has expanded to an extent never dreamed of by the older workers, so much so that no one can now claim to be an expert in more than one or two aspects of it. The era of the one-man book is ended. This is not peculiar to mineral metabolism. The last few years have seen the production of works edited by someone with general knowledge but contributed to by a panel of experts. These works, while, in general, useful, have often suffered from two disabilities—one, the unevenness of the various contributions, and the other, the obsolescence of some, if not the majority of the various chapters by the time of publication.

The present work is the first half of the first volume of a two-volume work, the successor to Shohl's book. The two editors have collected some fifty scientists who individually or collectively will be responsible for thirty-six chapters. There is no doubt, judging from the names of these contributors, that the work will be definitive. Volume I, of which the present book is Part A, treats the "physical and biological principles required for an analysis of the metabolism of minerals. Volume II will deal with the elements themselves".

Part A is entitled "Principles, Processes, and Systems". It is far more than an introduction to mineral metabolism and could be read to advantage by all biologists. The editors have cast their net wide and have included such subjects as thermodynamics and cybernetics. To one who has actively participated in one aspect of this subject, it is interesting to see how significant ancillary sciences have become.

To review this volume in the absence of the others is not easy. Judging from the projected contents of the rest, it is an extremely adequate introduction, possibly too much so. One hopes that the whole conspectus of mineral metabolism will be equally broad. For example, while stress is going to be laid on the hormonal control of mineral metabolism, there is no specific mention of nutritional influences, which are just as significant. However, this is for the future.

To turn now to specific mention of this volume: One must congratulate the editors on the up-to-dateness of the various contributions. In all cases, literature up to 1959 is cited and in some cases, papers published in 1960. The second to seventh chapters are on thermodynamic principles and concepts, cybernetic aspects of homeostasis, chelation, compartmental methods of kinetic analysis, ion transport, and body-fluid dynamics. The standard of writing in all is extremely high, and while the theoretical side is chiefly stressed, biological illustrations are freely used. Thus, the chapter on cybernetics uses the control of blood glucose as an example; many instances of biological ion transport are cited and the section on thermodynamics discusses the applicability of these laws to biological systems. The last three chapters are more biological, dealing with intestinal absorption and excretion, renal excretory mechanisms, and extrarenal changes of body constituents with the environment. These chapters your reviewer found most interesting and informative, and they should be read by all interested in such aspects in physiology.

Methods of handling mineral elements having thus been considered, the next volume, dealing with control of the elements and the tissues in which they occur, will be eagerly awaited.

A consideration of Chapter 1 has been deliberately left to the end of this review. It is by the doyen of mineral metabolism, Dr. Franklin C. McLean, and is entitled, "Homeostasis in Mineral Metabolism". Dr. McLean traces the history of the concept of homeostasis from Claude Bernard to the present day and gives instances of the homeostatic control of mineral metabolism. He has had the advantage of being able to peep into the as yet unpublished volumes and gives the reader an advance survey of what is to come. Written in Dr. McLean's pleasing style, this chapter forms an appropriate introduction to what promises to be a rather remarkable work.

J. T. Irving, M.D.

EXCISION OF PATHOLOGICAL DISC, AND FUSION

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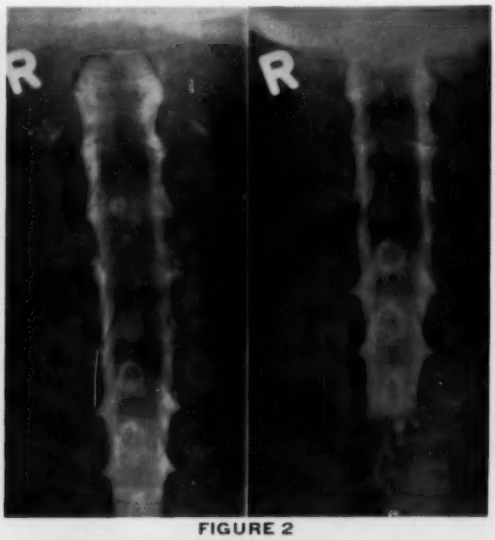
FIGURE 1



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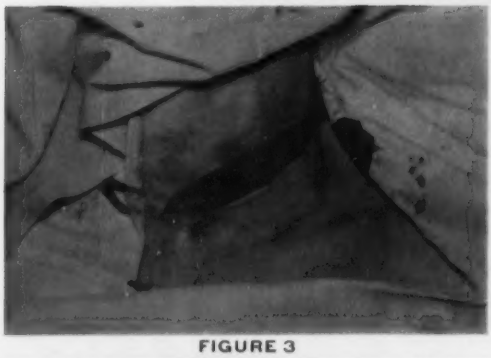

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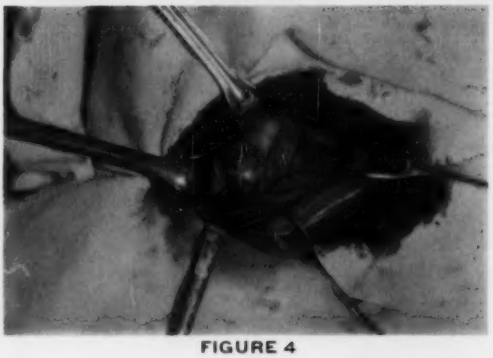

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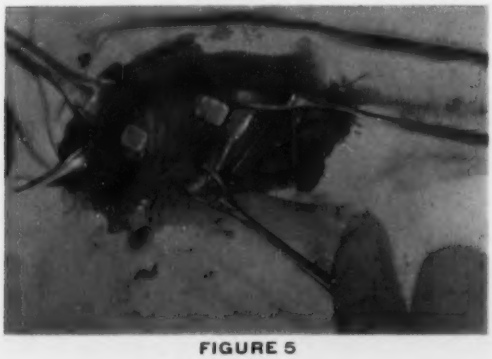

FIGURE 5

Figure 4: Exposure of vertebral column, sternocleidomastoid muscle and carotid sheath below and to the right; thyroid, trachea and esophagus above and to the left.

Figure 5: Insertion of needles for discogram. (Turn page for result.)

Note: Radiographs and photographs such as those reproduced here have many uses. They are invaluable to illustrate talks, lectures, classroom discussions. From original transparencies, black-and-white or color prints may be made to illustrate displays, articles for publication. And—remember always: The photographs you make today may be used tomorrow—years from now.

EXCISION OF PATHOLOGICAL DISC, AND FUSION (Continued)

FIGURE 6

Consider carefully the color photographs shown here. How significantly—objectively—they support the printed word. How vividly color defines tissue areas . . . clarifies the descriptive matter. Yet the cost of this material is small in terms of the aid it gives in teaching and research projects.

FIGURE 7

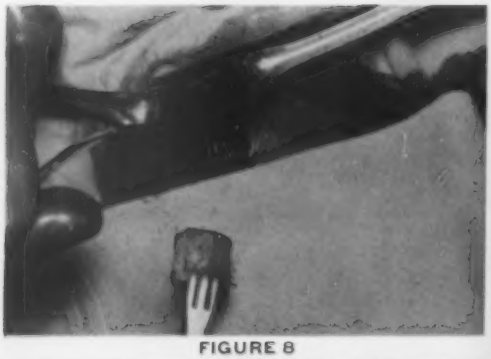

FIGURE 8

FIGURE 9

FIGURE 10

Figure 6: Discogram shows leakage of contrast medium posterior to bodies of C5 and C6. **Figure 7:** Excision of disc between C5 and C6. **Figure 8:** Bone graft from the right iliac crest shaped to fit disc space. **Figure 9:** Bone graft wedged into place between vertebral bodies of C5 and C6. **Figure 10:** Postoperative radiograph shows bone wedge in place.

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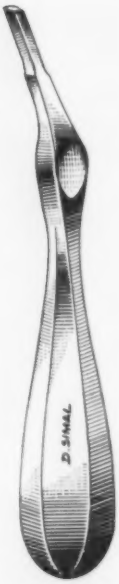

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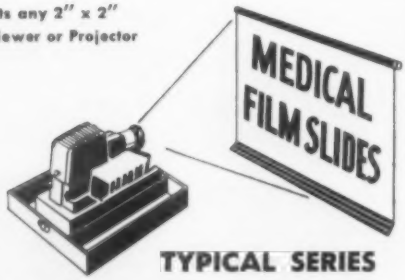

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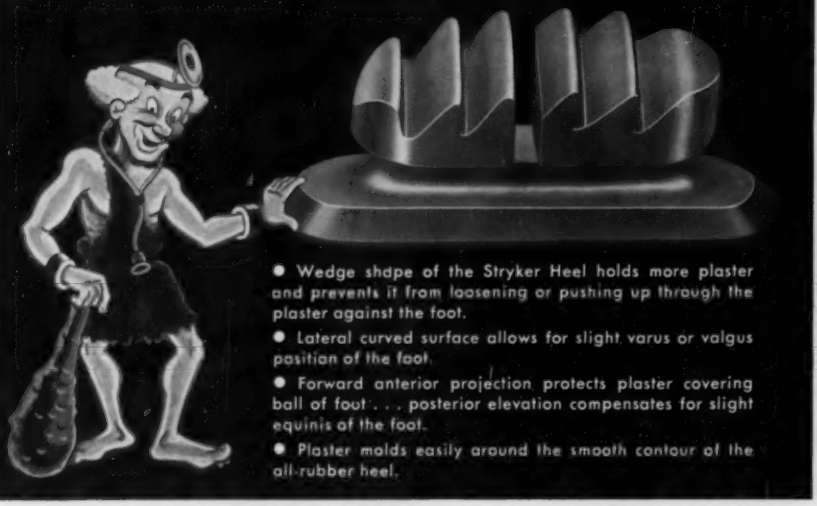

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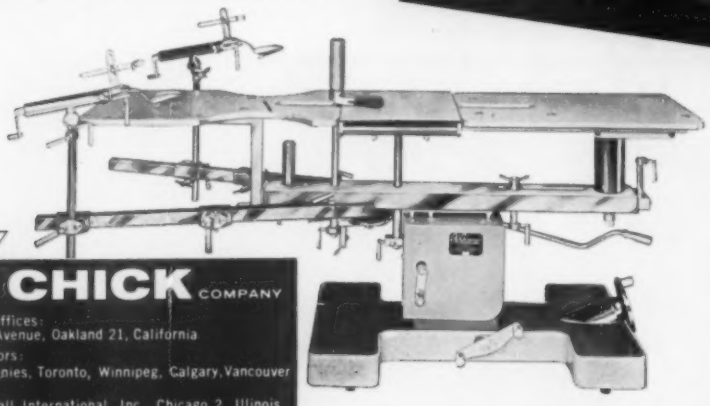

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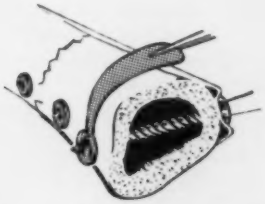

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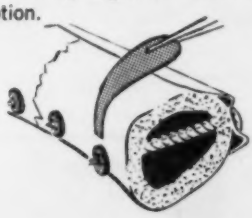

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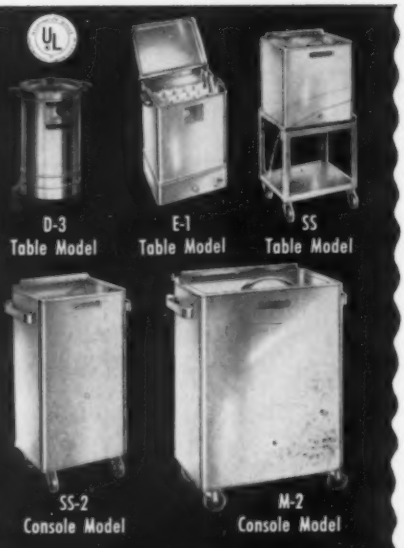

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